



Swedish University of Agricultural Sciences
Faculty of Natural Resources and Agricultural Sciences
Department of Economics

Price and Income Elasticities of Crude Oil Demand

The case of ten IEA countries

Christos Tsirimokos

Master thesis · 30 hec · Advanced level
Environmental Economics and Management · Master's Programme
Degree thesis No 705 · ISSN 1401-4084
Uppsala 2011

**Price and Income Elasticities of Crude Oil demand
The case of ten IEA countries**

Christos Tsirimokos

Supervisor: Rob Hart, Swedish University of Agricultural Sciences,
Department of Economics

Examiner: Yves Surry, Swedish University of Agricultural Sciences,
Department of Economics

Credits: 30 hec

Level: Advanced E

Course title: Degree Project in Economics

Course code: EX0537

Programme/Education: Environmental Economics and Management,
Master's Programme

Place of publication: Uppsala

Year of publication: 2011

Name of Series: Degree project

No: 705

ISSN 1401-4084

Online publication: <http://stud.epsilon.slu.se>

Key words: crude oil demand, oil prices, price elasticity, income elasticity,
Nerlove's partial adjustment model



Swedish University of Agricultural Sciences
Faculty of Natural Resources and Agricultural Sciences
Department of Economics

Abstract

This master thesis attempts to estimate the short-run and long-run price and income elasticities of crude oil demand in ten IEA member-countries for the time period 1980-2009. Specifically, the price and income elasticities for Sweden, Denmark, Spain, Portugal, Turkey, Finland, Italy, Germany, USA, and Japan are estimated. Crude oil consumption is a function of four explanatory variables: real oil prices, real GDP per capita, oil consumption lagged one year and a time trend representing technological improvements. The econometric model that is used is a multiple regression model derived from an adaption of Nerlove's partial adjustment model. Empirical results reveal that elasticities (both price and income) are lower in the short-run and hence more inelastic, indicating that countries need time to respond to changes in price or income. Econometric estimations illustrate that oil consumption is highly price inelastic both in short-run and long-run. Income elasticities are more elastic than price elasticities and close to unity in the long-run, indicating that countries are more sensitive to income changes.

Key words: crude oil demand, oil prices, price elasticity, income elasticity, Nerlove's partial adjustment model

Table of Contents

1. Introduction.....	1
2. Theoretical Background and Literature Review.....	4
2.1 The Structure of Economic Data-Types of Data.....	4
2.1.1 Cross-Sectional Data.....	4
2.1.2 Time Series Data.....	4
2.1.3 Panel Data.....	5
2.2 Dynamic Econometric Models.....	5
2.2.1 Autoregressive and Distributed lag Models.....	6
2.2.1.1 The Koyck Model.....	7
2.2.1.2 The Adaptive Expectations Model.....	8
2.2.1.3 The Partial Adjustment Model.....	9
2.2.2 Autoregressive and Distributed Lag Models (ARDL).....	10
2.2.2.1 Cointegration and the Error Correction Model (ECM).....	10
2.3 Literature Review.....	11
3. Choice of Model and Limitations.....	15
3.1 Choice of the Dynamic Econometric Model.....	15
3.2 Choice of Economic Data.....	16
3.3 Choice of Countries.....	18
3.4 Choice of Explanatory Variables.....	18
4. History of Crude Oil Market.....	20
4.1 Global Crude Oil Price Trends.....	20
4.2 Countries' Energy Sector and Review of Historic GDP/Oil Trends.....	24
4.2.1 Sweden.....	24
4.2.2 Denmark.....	27
4.2.3 Spain.....	29
4.2.4 Portugal.....	32
4.2.5 Turkey.....	35
4.2.6 Finland.....	37

4.2.7 Italy.....	40
4.2.8 Germany.....	42
4.2.9 United States of America.....	44
4.2.10 Japan.....	47
5. The Empirical model.....	50
5.1 The Regression Model.....	50
5.2 Tests of Autocorrelation.....	52
5.2.1 The Durbin-Watson d test and the h-test.....	53
5.2.2 The Breusch-Godfrey Lagrange Multiplier test.....	54
5.3 Remedial Measures for Autocorrelation.....	55
5.3.1 The Cochrane-Orcutt iterative procedure.....	57
5.4 Empirical Findings and Analysis.....	58
6. Conclusion and Discussion.....	65
Appendix A.....	67
Appendix B.....	69
Appendix C.....	77
Bibliography.....	79

1. Introduction

Modern society is heavily reliant upon fossil fuels and especially oil. More than any other energy resource (natural gas, nuclear power etc.) oil has powered the great economic boom of the past century and continues to drive the global economy affecting every aspect of daily life. According to Xiong and Wu (2009) oil can be considered as a high-quality energy resource which plays a key role in economic development. According to Cooper (2003) oil fuels almost every sector of the modern industrialized economy and continues to occupy a pre-eminent position at the heart of the world economy.

Transportation, industry, agriculture, communications, commercial and public services are fuelled by oil. According to Hirsch (2005) oil fuels the vast majority of the world's mechanized transportation equipment; automobiles, trucks, airplanes, trains, ships, farm equipment, the military and it is the primary feedstock for many of the chemicals that are essential to modern life. It is estimated that 61.4 percent of the world's oil is used for transport, 16.2 percent for non-energy use, 9.5 percent in industry and 12.9 percent in other sectors such as agriculture, residential, public and commercial services (IEA, 2010b). Additionally, oil is the primary feedstock for the petrochemical industry and the basic raw material for a big number of consumer products such as plastics, soaps, detergents, polyester clothing electronic devices, fertilizers etc. Globally, the only sources of net increase in demand over the past three decades have been transportation (road, aviation and marine) and the petrochemicals sector (OPEC, 2010).

During the recent decades, world oil production has increased dramatically. But as countries' energy needs increase (and there are not adequate substitutes for oil) the world oil demand and the global oil production increase respectively. Figure 1.1 illustrates the historic evolution of global oil production and consumption from 1980 to 2009. As can be observed there is an upward trend both in oil production and oil consumption. According to BP (2010) the crude oil production for 2009 was 79,948 barrels/day and the oil consumption for that year was 84,077 barrels/day.

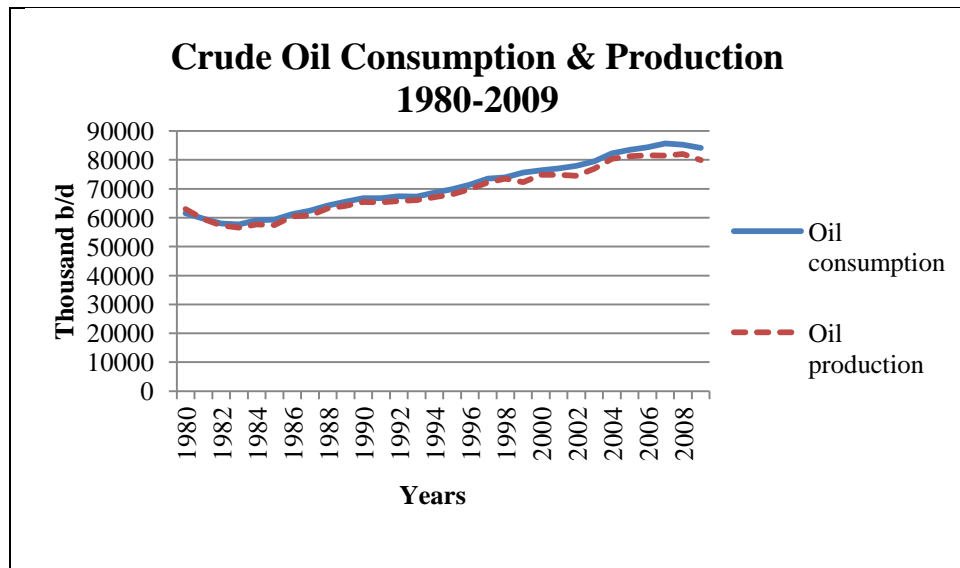


Figure 1.1: Global Crude Oil Production and Consumption 1980-2009

Source: BP, World Energy Statistical Review, 2010

It can be concluded from the facts above that oil is a crucial matter for the economic development and prosperity. It is very useful for the governments and policy makers to know how the demand for crude oil responds to changes in price and income. Especially, in the existence of a global economic recession, such as the ones that many countries experience in recent years, policy makers should be aware about the responsiveness or sensitivity of crude oil demand to changes in price and income. This master thesis attempts to derive the price and income elasticities of demand for crude oil both in the short-run and in the long-run in these IEA member countries. The countries that have been included in this study are: Sweden, Denmark, Spain, Portugal, Turkey, Finland, Italy, Germany, USA, and Japan. For that reason an econometric analysis is conducted using annual time series data that cover the time period 1980-2009.

Econometric analysis indicates that the price elasticity of demand for crude oil is significantly low both in the short and the long-term. Income elasticity on the other hand is found to be inelastic (short-run) or elastic and near unity in some cases (long-run). As expected the long-run elasticities values (price and income) are larger than

The organization of the thesis is as follows. Chapter 2 provides to the reader the theoretical background of this study. In chapter 3 the choice of the theoretical model is illustrated. Chapter 4 presents a brief account of the history of crude oil prices and describes countries' energy sector along with historic Oil/GDP trends. Chapter 5

explains the methodology that is used in this study and presents the empirical findings of the thesis. Finally, chapter 6 includes the conclusions and some suggestions for further research.

2. Theoretical Background and Literature Review

This chapter provides the theoretical background of this study. The first section presents the types of economic data. The second section introduces the dynamic econometric models. The last section of this chapter presents some studies on the estimation of crude oil demand.

2.1 The Structure of Economic Data – Types of Data

An econometric analysis requires data. There are three types of data that someone could encounter in an applied econometric analysis: Cross–Sectional, Time Series, and pooled data. The latter is a combination of cross-sectional and time series data.

2.1.1 Cross-Sectional Data

Cross-Sectional data are data collected at one point in time. A cross sectional-data set consists of a sample of individuals, households, firms, countries or a variety of other units, taken at a given point in time (Wooldridge, 2009). Although cross-sectional data are widely used in economics (especially in the field of microeconomics) they present the problem of heterogeneity. An example of an econometric model than analyses cross-sectional data is:

$$Y_i = \beta_1 + \beta_2 X_{2i} + \beta_3 X_{3i} + \cdots + \beta_k X_{ki} + u_i, \quad (2.1)$$

where $i = 1, 2, \dots, k$ observations.

2.1.2 Time Series Data

Time Series data are data collected over a period of time. A time series is a set of observations on the values that a variable takes at different times (Gujarati, 2009). Examples of time series data include stock prices, unemployment rate, gross domestic product, consumer price index, money supply etc. The time intervals that the time series data can be collected could be daily, weekly, monthly, quarterly or annually. Those time intervals are the most common use in economics although there are some time series data that recorded less frequently such as every ten years. Examples of

time series model are the static model (equation 2.2), the dynamic or autoregressive model (equation 2.3), and the distributed-lag model (equation 2.4) which are presented below. Thus,

$$Y_t = \beta_0 + \beta_1 X_t + u_t, \quad (2.2)$$

represents a static model, whereas

$$Y_t = \beta_0 + \beta_1 X_{t-1} + \beta_2 X_{t-2} + u_t, \quad (2.3)$$

is a distributed-lag model and,

$$Y_t = \beta_0 + \beta_1 X_t + \beta_2 Y_{t-1} + u_t, \quad (2.4)$$

is an example of an autoregressive model.

2.1.3 Panel Data

Panel data combine elements for both time series and cross-sectional data. In other words, panel data sets have both cross-sectional and time series features (Wooldridge, 2009). In a panel data the same cross sectional unit (e.g. a country) is surveyed over time (Gujarati, 2009). According to Gujarati (2009), there are other names for panel data, such as pooled data, combination of time series and cross sectional data and micropanel data. The following model is an example of a panel data model:

$$Y_{it} = \beta_0 + \beta_1 X_{it} + \beta_2 Z_{it} + \beta_3 Q_{it} + u_t, \quad (2.5)$$

where $i = 1, 2, \dots, k$ observations and $t = 1, 2, \dots, n$ time periods. As we can see panel data have two dimensions: space and time.

2.2 Dynamic Econometric Models

There are many econometric models that include values of the explanatory variables in the regression equation. Those models are known as dynamic or lagged regression models. There are two types of lagged (dynamic) models: the distributed-lag and the autoregressive model. If the regression model includes lagged value(s) of the explanatory variable(s) it is called distributed-lag, while if the model includes lagged

value(s) of the dependent variable among its independent variables it is called autoregressive.

2.2.1 Autoregressive and Distributed – lag Models

An example of an autoregressive model can be given by equation (2.5):

$$Y_t = \alpha + \alpha\beta X_t + \gamma Y_{t-1} + u_t. \quad (2.5)$$

On the other hand, equation (2.6) represents a distributed-lag model. Thus:

$$Y_t = \alpha + \beta_0 X_t + \beta_1 X_{t-1} + \beta_2 X_{t-2} + u_t, \quad (2.6)$$

Equation (2.7) represents an infinite lag model since the length of the lag is unspecified. On the other hand, if the length of the lag is specified the model is known as a finite lag distributed and is given by equation (2.8) which the length of the lag is equal to κ .

$$Y_t = \alpha + \beta_0 X_t + \beta_1 X_{t-1} + \beta_2 X_{t-2} + \dots + u_t. \quad (2.7)$$

On the other hand, if the length of the lag is specified the model is known as a finite lag distributed and is given by equation (2.8) which the length of the lag is equal to κ .

$$Y_t = \alpha + \beta_0 X_t + \beta_1 X_{t-1} + \beta_2 X_{t-2} + \dots + \beta_\kappa X_{t-\kappa} + u_t. \quad (2.8)$$

The coefficient β_0 is known as the short-run multiplier since is the partial derivative of Y with respect to X , implying the change in the mean value of Y following by a unit change in X in the same time period (Gujarati, 2009).

Similarly, β_1 is the partial derivative of Y with respect to X_{t-1} and so forth. If the change in X is maintained at the same level, $(\beta_0 + \beta_1)$ gives the change in Y in the next period, $(\beta_0 + \beta_1 + \beta_2)$ in the following period and so on. These partial sums are called intermediate multipliers (Gujarati, 2009).

According to Gujarati (2009) the long-run distributed –lag multiplier is given by:

$$\Sigma\beta_i = \beta_0 + \beta_1 + \beta_2 + \dots + \beta_\kappa = \beta.$$

By defining:

$$\beta_i = \frac{\beta_i}{\sum_{i=0}^{\infty} \beta_i} = \frac{\beta_i}{\beta}, \quad (2.9)$$

we normalize these β_i 's by their sum and we get the proportion of the long-run impact (Baltagi, 2008).

In the following paragraphs three autoregressive models are presented: the Koyck model, the adaptive expectations and the partial adjustment model. All these models have the form of equation (2.5) meaning that all of them are autoregressive in nature.

2.2.1.1 The Koyck Model

In equation (2.7) β 's are all of the same sign and it is assumed that they decline geometrically as follows:

$$\beta_k = \beta_0 \lambda^k, \quad (2.10)$$

where $0 < \lambda < 1$ is the rate of decline of distributed lag and $(1 - \lambda)$ is the speed of adjustment (Gujarati, 2009). Equation (2.10) shows that as one goes back into the distant past the effect of that lag on Y_t becomes progressively smaller – each successive β coefficient is numerically less than each preceding β (Gujarati, 2009).

Due to equation (2.10), the infinite lag model of equation (2.7) can be written as follows:

$$Y_t = \alpha + \beta_0 X_t + \beta_0 \lambda X_{t-1} + \beta_0 \lambda^2 X_{t-2} + \dots + u_t, \quad (2.11)$$

According to Gujarati (2009), Koyck postulate that if we lag equation (2.11) by one period and then we multiply the obtained lag equation by λ we get:

$$\lambda Y_{t-1} = \lambda \alpha + \lambda \beta_0 X_{t-1} + \beta_0 \lambda^2 X_{t-2} + \beta_0 \lambda^3 X_{t-3} + \dots + \lambda u_{t-1}. \quad (2.12)$$

By subtracting equation (2.12) from equation (2.11) we get:

$$Y_t = \alpha(1 - \lambda) + \beta_0 X_t + \lambda Y_{t-1} + v_t, \quad (2.13)$$

where $v_t = (u_t - \lambda u_{t-1})$. Equation (2.13) represents the Koyck model. Comparing equation (2.13) with equation (2.7) we can see that in equation (2.7) we had to estimate the constant α and an infinite number of β 's but by doing the Koyck

transformation , in equation (2.13) we have only three unknowns to estimate and specifically α , β_0 and λ . A purely distributed-lag model presents the problem of multicollinearity since successive lagged values of the independent variables tend to be correlated, as a result the Koyck transformation help us to resolve that problem by transforming a distributed-lag model into an autoregressive model.

2.2.1.2 The Adaptive Expectations Model

Suppose that the demand for money Y_t is a fraction of the expected long-run rate of interest X_t (Gujarati, 2009). Thus:

$$Y_t = \beta_0 + \beta_1 X_t^* + u_t. \quad (2.14)$$

Expected long-run rate of interest is updated according to the following method:

$$X_t^* - X_{t-1}^* = \gamma(X_t - X_{t-1}^*), \quad (2.15)$$

or

$$X_t^* = \gamma X_t + (1 - \gamma)X_{t-1}^*, \quad (2.16)$$

where $0 < \gamma \leq 1$ is known as the coefficient of expectation (Gujarati, 2009). Equation (2.15) or equation (2.16) is known as the adaptive expectation model and postulates that the expectations about the rate of interest are revised each period by a fraction γ of the gap between the current value of the variable and its previous expected value (Gujarati, 2009).

By substituting equation (2.16) into (2.14) and doing some algebraic manipulations we obtain:

$$Y_t = \gamma\beta_0 + \gamma\beta_1 X_t + (1 - \gamma)Y_{t-1} + v_t, \quad (2.17)$$

where $v_t = u_t - (1 - \gamma)u_{t-1}$.

In equation (2.14) coefficient β_1 measures the long-run value of the variable X whereas in equation (2.17) $\gamma\beta_1$ measures the average response of Y to a unit change in the actual or observed value of X (Gujarati, 2009). If $\gamma=1$ then the actual and the long-run values of X are the same.

2.2.1.3 The Partial Adjustment Model

The partial adjustment model has been provided by Nerlove (1956) and is based on the accelerator model of economic theory. We assume that there is a long-run amount of capital stock Y^* needed to produce a given output X . Thus:

$$Y_t^* = \beta_0 + \beta_1 X_t + u_t. \quad (2.18)$$

Equation represents the long-run demand for capital stock (Gujarati, 2009). Due to the fact that the long-run level of capital is not directly observable, Nerlove introduces the partial adjustment hypothesis (Gujarati, 2009). That is:

$$Y_t - Y_{t-1} = \delta(Y_t^* - Y_{t-1}), \quad (2.19)$$

where $0 < \delta \leq 1$ is the adjustment coefficient, $(Y_t - Y_{t-1})$ is the actual change and $(Y_t^* - Y_{t-1})$ is the desired change (Gujarati, 2009).

Equation can be written as:

$$Y_t = \delta Y_t^* + (1 - \delta)Y_{t-1}, \quad (2.20)$$

Equation (2.20) says that the actual capital stock at time t is a weighted average of the long-run capital stock and the capital stock lagged one period (Gujarati, 2009).

By substituting equation (2.18) into (2.20) we get:

$$Y_t = \delta\beta_1 X_t + (1 - \delta)Y_{t-1} + \delta u_t. \quad (2.21)$$

Equation (2.21) describes the partial adjustment model and can be called the short-run demand function for capital stock (Gujarati, 2009).

By estimating equation (2.21) we obtain the estimated coefficient of adjustment δ . Then, we can easily derive the long-run function by dividing $\delta\beta_0$ and $\delta\beta_1$ by δ and omitting the lagged Y term which will then give equation (2.18) – the long-run demand function of capital stock (Gujarati, 2009).

2.2.2 Autoregressive Distributed lag Models (ARDL)

ARDL model is an econometric dynamic model in which the independent variables influence the dependent variable with a time lag and at the same time the dependent variable is correlated with lag(s) of itself. According to (Baltagi, 2008) the simplest form of an ARDL model is given by:

$$Y_t = \alpha + \lambda Y_{t-1} + \beta_0 X_t + \beta_1 X_t + u_t, \quad (2.22)$$

where both Y_t and X_t are lagged once.

Although ARDL modelling has been used for a long time, Pesaran and Shin (1999) and Pesaran et al (2001) introduced the bounds test for cointegration that can be employed within an ARDL specification (Altinay, 2007).

The ARDL approach includes two steps for estimating the long-run relationship (Altinay, 2007). In the first step the existence of a long-run relationship among all variables is examined. If the variables exists a long-run cointegration an ECM is established for examining the short-run adjustment (Ghosh, 2009).

2.2.2.1 Cointegration and the Error Correction Model (ECM)

Regression of one time series variable on one or more time series variables often can give nonessential or spurious results. One way to guard against, it is to find out if the time series are cointegrated (Gujarati, 2009).

Consider the following model:

$$Y_t = \beta X_t + u_t. \quad (2.23)$$

For simplicity, we do not include a constant parameter. We assume that the two variables (X and Y) are integrated of order one, meaning that they contain a stochastic trend (Gujarati, 2009).

Rearranging equation (2.23) we get:

$$u_t = Y_t - \beta X_t. \quad (2.24)$$

Assume that we subject u_t in equation (2.24) to a unit root analysis and we find that it is stationary, meaning that u_t is integrated of order zero. As a result, a regression of Y to X as in equation (2.23) would be meaningful (not spurious). In such a case the two variables are cointegrated and a regression such as equation (2.23) is called a cointegrating regression with coefficient β as the cointegrating parameter (Gujarati, 2009). According to Gujarati (2009), two variables are cointegrated if they have a long-term relationship between them.

Two steps are used for finding out if two or more time series are cointegrated. Those tests are the Engle-Granger and the augmented Engle-Granger test.¹

An important issue in econometrics is the need to integrate short-run dynamics with long-run equilibrium (Maddala, 1988). The cointegrating regression so far considers only the long-run property of the model without dealing with the short-run dynamics (Gujarati, 2009). ECM is an approach of modelling short-run disequilibrium. Given equation (23) and (24) we define an ECM as:

$$\Delta Y_t = \alpha u_{t-1} + \gamma \Delta x_t + \varepsilon_t, \quad (2.25)$$

where ε_t is a white noise error term and u_{t-1} is the lagged value of the error term in equation (2.24).

The ECM equation says that ΔY_t can be explained by the lagged error term u_{t-1} and the first difference in X_t , ΔX_t . The term u_{t-1} can be thought as an equilibrium error occurred in the previous period. If that term is nonzero the model is out of equilibrium and vice versa (Gujarati, 2009). The ECM has both long-run and short-run properties built in it, since parameter β is the long-run parameter and α and γ are the short-run parameters (Gujarati, 2009).

2.3 Literature Review

There are numerous academic studies that examine the demand of energy in different countries or regions. On the other hand, fewer studies can be found on the demand of crude oil. The majority of the empirical studies examine the demand for crude oil in a

¹ Due to the limited extent of this study we decided to not illustrate these tests. For an analysis and explanation of these two tests, reader can see at Gujarati (2009): Basic Econometrics, McGraw Hill.

group of countries (for instance, OECD and non-OECD countries) by using the same econometric model.

Altinay (2007) estimated short and long-run elasticities of demand for crude oil in Turkey for the time-span 1980-2005 by using the methodology of the autoregressive distributed lag (ARDL) bounds testing approach to cointegration. The demand for oil is modeled as a function of oil prices, income and dummy variables. He estimated that the price elasticities of import demand for crude oil in Turkey in the short-run and in the long run are -0.10 (significant) and -0.18 (significant), respectively, implying that the price demand for crude oil in Turkey (short-run and long-run) is inelastic. The estimation about income elasticities does not vary a lot in the short-run and in the long-run. He found that the income elasticity in the short-run is 0.64 (significant) and in the long run 0.61 (significant). Those variables indicate that the demand for oil is income inelastic.

Ghosh (2007) examined the long-run equilibrium relationship among the quantity of imported crude oil, price of crude oil and real income in India for the period 1970-1971 and 2005-2006. The method that is used is an autoregressive distributed lag (ARDL) bounds testing approach of cointegration. Results indicate an inelastic price demand in the long-run. Specifically the long-run price elasticity of demand is -0.63 (statistically insignificant). On the other hand the long term income elasticity is 1.97 (statistically significant).

Krichene (2002) analyzed the world demand and supply of crude oil and natural gas over the period 1918-1999. He used a simultaneous demand and supply model for world crude oil and natural gas. The model is estimated by a two-stage least squares method and is reestimated in an error correction model (ECM). He found that the short-run price elasticity of world demand of crude oil is -0.06 in 1918-1999, -0.08 in 1918-1973 and -0.02 in 1973-1999. The results are statistically non-significant except for the period 1918-1999. Regarding the short-run income elasticities, he found that in period 1918-1999 income elasticity is 0.53 (significant), in period 1918-1973 is 0.42 (significant) and 1.45 (significant) in period 1973-1999. He reestimated the elasticities by using a different time series econometric technique (ECM) and he found similar results. The long-run price elasticity is significantly low and it is equal to -0.05, -0.13, -

0.005 in periods 1918-1999, 1918-1973 and 1973-1999 respectively. Income elasticity estimated at 0.6 in 1918-1999, 1.8 in 1918-1973 and 1.2 in 1973-1999.

Dees et al (2007) analyzed the oil market development and risks by using a structural econometric model of the world oil market. The dynamic ordinary least-squares method is used for the estimation of the long-run coefficients while the error correction model (ECM) is used for the estimation of short-run dynamics. They found that long-run income elasticities range from 0.17 to 0.98 while in the short-run those elasticities range from 0.0001 to 0.82. On the other hand the short-run price elasticities are very inelastic approaching zero.

Cooper (2003) estimated the short-run and the long-run price elasticities for 23 countries over the period 1979-2000 by using a multiple regression model derived from an adaption of Nerlove's partial adjustment model. The oil demand is considered to be a function of oil price, GDP and a lagged oil consumption variable. He found that short-run price elasticity of demand for crude oil ranges from +0.023 to -0.109 implying that oil demand is price inelastic. On the other hand price elasticity in the long-run ranges from +0.038 to -0.568.

Ziramba (2010) examined the long-run and the short-run price and income elasticities of crude oil demand in South Africa using time series that cover the time period 1980-2006. The methodology employed in the study is the Johansen cointegration multivariate analysis. He estimated that the long-run price elasticity is statistically significant and equals to -0.147. The long-run income elasticity is also statistically significant and estimated to be equal to 0.429. Both elasticities show that the demand for crude oil is income and price inelastic.

Xiong and Wu (2009) examined and forecasted the crude oil demand in China for the time span 1979-2004 and 2008-2020, respectively. They assumed that four factors affect crude oil demand: GDP, population growth, the share of industrial sector in GDP and the oil price. The Johansen cointegration test and an error correction model (ECM) are used for the estimation of elasticities. They estimated an income elasticity of 0.647 and a price elasticity of -0.365.

Narayan and Smyth (2007) estimated the long-run price and income elasticities for oil in the Middle-East for the period 1971-2002 by applying panel unit root and panel

cointegration techniques. It has been indicated that demand for oil in the Middle East is price inelastic and income elastic. The long-run price elasticities range from -0.071 to -0.002 and the long-run income elasticities range from 0.204 to 1.816.

Ghouri (2001) analyzed oil demand in USA, Canada and Mexico for the period 1980-1999. The Almon polynomial distributed lag model is used for the estimation of elasticities. He found that long-run income elasticity is 0.98, 1.08 and 0.84 in USA, Canada and Mexico, respectively. The price elasticity in the long-run is inelastic and has been estimated greater in absolute values than the short-run implying that consumers are more sensitive to prices change in the long term than in the short term.

Finally, Gately and Huntington (2001) analyzed the determinants of oil demand for OECD and non-OECD countries by examining the asymmetric effects of oil price and income changes on the demand for energy and oil. They found that the long-run income and price elasticities of demand for oil for OECD countries are 0.56 and -0.64 respectively. For non-OECD countries they estimated that the long-run price elasticity is -0.18 and income elasticity accounts for 0.53.

3. Choice of Model and Limitations

This chapter mainly explains the reasons for choosing the partial adjustment model along with some limitations of its. The other sections of this chapter explain the reasons of choosing the time series data, the ten IEA member-countries and the factors that affect countries' crude oil demand.

3.1 Choice of the Dynamic Econometric Model

Time lags play an important role in economics. Due to lags, short-run price and income elasticities are generally smaller (in absolute value) than the associated long-run elasticities. According to Gujarati (2009), there are three main reasons for using time lags. These reasons are: psychological, technological and institutional.

In order to capture the evolution of energy use over time a dynamic framework is needed (Olsen, 1988). In paragraph 2.2 various dynamic econometric models has been discussed. In this study an adaption of Nerlove's partial adjustment model has been chosen for the estimation of the short-run and the long-run elasticities of demand for crude oil.

Partial Adjustment model presents some advantages and limitations. An attractive feature of partial adjustment model is the easily derivation of price and income elasticities. Specifically, short-run and long-run elasticities of demand can be directly estimated. More precisely long-run price and income elasticities can be estimated from available short-run data. On the other hand in an ARDL model which is a general dynamic specification the short-run effects can be directly estimated and the long-run equilibrium relationship can be indirectly estimated (Altinay, 2007).

As it has been stated in paragraph 2.2 Koyck, adaptive expectations and partial adjustment model are all autoregressive in nature. Partial adjustment model, however, has a much simpler error term. According to Gujarati (2009), although similar in appearance adaptive expectations and partial adjustment model are conceptually very different since adaptive expectations model is based on uncertainty and partial adjustment model is based on technical or institutional rigidities, inertia, cost of change etc.

According to Gujarati (2009), a significant advantage of partial adjustment model over the Koyck and the adaptive expectation model is that partial adjustment model can be estimated by the usual ordinary least square (OLS) procedure without yielding inconsistent estimates. Koyck and adaptive expectations model on the other hand cannot be estimated by the usual OLS procedure and other estimation methods need to be devised.

Partial adjustment model presents some limitations. According to Thiele (2000), a fundamental weakness of the partial adjustment model is the dynamics of supply which comes down to the crude decision rule that in each period a fraction of the difference between the current capital stock and the long-run desired capital stock is eliminated (see equation 2.19). According to Thiele (2000), partial adjustment model is unlikely to capture the full dynamics of supply, thus biasing elasticities estimates downwards. As stated in Thiele (2000), some alternative approaches can be used to overcome the restrictive dynamic specification of the partial adjustment model. One of these methods is the cointegration analysis. Cointegration has been discussed in paragraph 2.2 and does not impose any restrictions on the short-run behavior of time series variables. If variables are cointegrated there is an error correction model which incorporates both short-run and long-run behavior.

According to Gujarati, (2009), a researcher must be extremely careful in telling the reader which model he or she is using. Thus researchers must specify the theoretical underpinning of their model. The theoretical underpinning of the model used in this thesis is provided in the next paragraph.

3.2 Choice of Economic Data

In paragraph 2.1 we have illustrated in brief the types of economic data which are used in an econometric analysis. Specifically three types of data have been discussed: cross-sectional, time series and panel. In cross-sectional data, values of one or more variables are collected for several sample units at the same point in time while in time series data we observe the values of one or more variables over a period of time (Gujarati, 2009). In panel data the same cross-sectional unit is surveyed over time (Gujarati, 2009).

In this study the estimation of the demand for crude oil in ten countries is based on time series data using a country-by-country basis. Alternatively, someone could analyze the demand for crude oil by using a panel data approach. According to Olsen (1988), in order to fit a long term demand relation for energy, either cross section data or panel data should be used, since these two types of data tend to capture differences between "states" that have remained stable for some time. On the other hand, the employ of pure time series figures are believed to imply that the estimates are strongly influenced by short term fluctuations in the included variables.

The use of panel data offers to the researchers and econometricians many advantages. However, because panel data include both cross-sectional and time series dimensions the application of regression models to fit econometric models are more complex than those for simple time series data sets.

The use of time series, help us to forecast future values of a time series, assess the impact of a single event and analyze causal patterns. Forecasting is an important part of econometric analysis. Gujarati (2009), discussed two methods of forecasting that are quite popular: the Box-Jenkins methodology and the vector autoregression. By using a time series approach we can analyze the impact of a single event such as the impact of oil prices on a country's GDP. Finally, the employ of time series data give us the possibility to analyze causal patterns. According to Gujarati (2009), the existence of a relationship between variables does not prove causality or the direction of influence, however, in regressions involving time series data the situation may be different because events in the past can cause events to happen today but future events cannot.

However, there are some problems that arise when we use time series data. These problems can be solved by the use of a panel data approach. Baltagi (2005), have listed some advantages of panel data over time series data. Panel data give more variability, less collinearity among the explanatory variables, more degrees of freedom and more variation in the data leading to more efficient estimators. Furthermore, with panel data we can test more complicated behavioral models than a single time series. For instance, phenomena such as economies of scale and technological change can be better studied by a panel data approach. However, as

stated in Baltagi (2005), panel data is not a panacea and will not solve all the problems that a time series approach cannot handle.

3.3 Choice of Countries

As it has been stated ten economies has been included in this study for the estimation of elasticities. Sweden is chosen since it is a country with low share of crude oil in its energy mix and had the vision of being the first oil-independent country in the future (Commission on Oil Independence, 2006). Denmark is interesting for analyzing since it is a country which has reduced the use of oil in recent years and has set the goal of being fossil-fuel free in the following years (Danish Commission on Energy Climate Policy, 2010). Moreover, since both countries are among the richest economies in Europe in terms of real GDP per capita we find it interesting to include them in this thesis. Spain, as well as Portugal and Turkey have been included to this thesis as have experienced great crude oil consumption over the past thirty years. Finland is appealing for investigation since it is a country with a high share of renewable resources in its energy mix. Germany is a modern and technologically advanced economy (the biggest economy in terms of total GDP in Europe in 2009) and therefore interesting to analyse. Italy is included in this study because has limited domestic energy sources and is heavily depends on energy imports. USA is the largest crude oil consumer in the world and seems appealing to include it in the research. Japan has been selected since it is the third crude oil consumer globally and has experienced great economic growth the later years.

3.4 Choice of Explanatory Variables

According to Xiong and Wu (2008) crude oil demand includes the amount of crude oil that people are willing and able to purchase in a specific period but since there is no statistical information about it, crude oil consumption used similar to crude oil demand.

The factors that could affect oil consumption for this study are real GDP per capita, real crude oil prices, oil consumption lagged one year and a time trend. The Arabian light crude oil prices (1980–1983) and the Brent crude oil prices (1984 – 2009) are in real terms (base year 2009) and expressed in current US \$. The oil price that has been

used is the world oil price in the sense that it is the producer price and does not include taxes or subsidies. The producer's price indices for petroleum industry are used to represent oil price (Xiong and Wu, 2008).

In the academic literature the crude oil consumption is a function of several other explanatory variables such as innovations and energy policies. Due to the fact that such variables are difficult to quantify we include only four variables that could affect crude oil consumption.

4 History of Crude Oil Market

This chapter introduces to the reader the historical oil, price and GDP trends. Section 4.1 presents the history of crude oil prices for the time period 1918-2009 while section 4.2 describes the energy sector of each country along with historic Oil/GDP trends.

4.1 Global Oil Price Trends

Price for all products is determined by the law of supply and demand. The same holds for crude oil. The price of crude oil, the raw material from which petroleum products are made, is established by the supply and demand conditions in the global market overall².

Crude oil prices behave much as any other commodity with wide price swings in times of shortage or oversupply³. According to economic theory, resources that are in scarce supply tend to have high prices. However, as stated in Jones (2002) the prices (relative to wages) of nonrenewable resources-in this study crude oil-seem to be declining or to be slightly constant in the long run. This is true until 1970 where oil price was stable and declining. But since 1970 oil price has been highly unstable. According to Kaufmann et al (2008), in the decade of 1950 and 1960 was excess capacity of crude oil and as a result Texas Railroad Commission (the dominant producer) pump crude oil only nine days per month. That decision lead to the maintenance of oil supply-demand balance. But the situation changed in 1970. OPEC has a different political agenda than the Texas Railroad Commission and price volatility increased tremendously (Dees et al, 2007).

Four subperiods have been selected for the analysis of Crude Oil Prices: 1918-1973, 1973-1985, 1986-1999, and 2000-2009. According to Dees et al (2007) the choice of the first three periods is based on the stability of the world economy in 1918-1973 and the oil price shocks that world experienced from 1973 until 1981 as well as the price

² U.S Energy Information Agency (EIA), Oil Market Basics, downloaded on 18/08/2011 by: http://www.eia.gov/pub/oil_gas/petroleum/analysis_publications/oil_market_basics/default.htm

³ WTRG Economics, Oil Price History and Analysis, downloaded on 18/08/2011 by: <http://www.wtrg.com/prices.htm>

volatility that followed after. The fourth distinct subperiod 2000-2009 has been chosen since 2001 oil prices have increased year on year until 2008.

In the period 1918-1973 prices exhibited remarkable long-term stability, with both nominal and real prices. In figure 4.1 we can see the real and nominal crude oil price pattern for the examination period 1918-1973. In 1931 (the Great Depression) nominal oil price was \$0.65 which was the lowest price value and reached a peak of 3.29\$ in 1973.

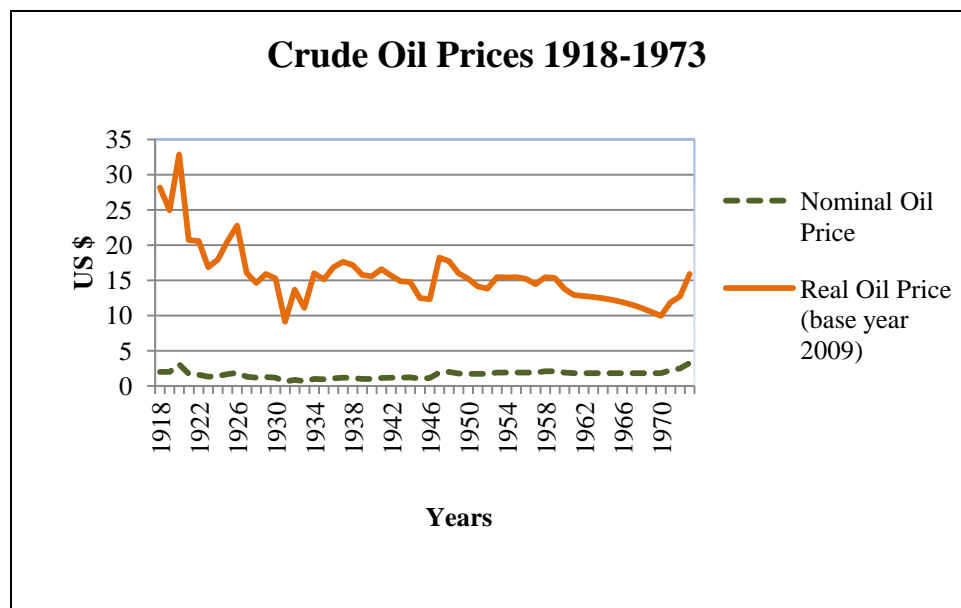


Figure 4.1: Real and nominal Crude Oil price 1918-1973
Source: BP-Statistical Review of World Energy, 2010

In the second examination period 1973-1985, the world experienced two great oil price shocks: the major oil crisis in 1973 and the oil price shock in 1979. In 1973 the oil market moved from a competitive system to a cartel structure (Krichene, 2002).

The Yom Kippur War started with an attack on Israel by Syria and Egypt on October of 1973. The United States and many countries in the western world showed support for Israel. Because of this support, several Arab exporting nations and Iran imposed an embargo on the countries supporting Israel⁴. OPEC stopped oil exports to countries that supported Israel (for example, the United States and the Netherlands) and the panic and reallocation of supply caused prices to rise more than 250 percent from 1972 to 1974 (Kaufmann et al, 2008).

⁴ WTRG Economics, Oil Price History and Analysis, downloaded on 18/08/2011 by:
<http://www.wtrg.com/prices.htm>

Figure 4.2 indicates the nominal and the real oil prices for the time span 1973-1985. In 1973 the crude oil price was \$3.29 in nominal terms and after one year price increased to \$11.58. A very important explanation about the increase of oil prices in 1973 is given by Adelman (2002). According to him, in the period 1971-1973 OPEC increased many times the excise tax and for each increase oil companies raised the oil prices.

From 1974 to 1978, the world crude oil price was relatively flat ranging from \$11.58 per barrel to \$14.02 per barrel. When adjusted for inflation world oil prices were in a period of moderate decline. In 1975–1978 they again cut output and raised taxes and prices but worldwide inflation soon offset these smaller price increases (Adelman, 2002).

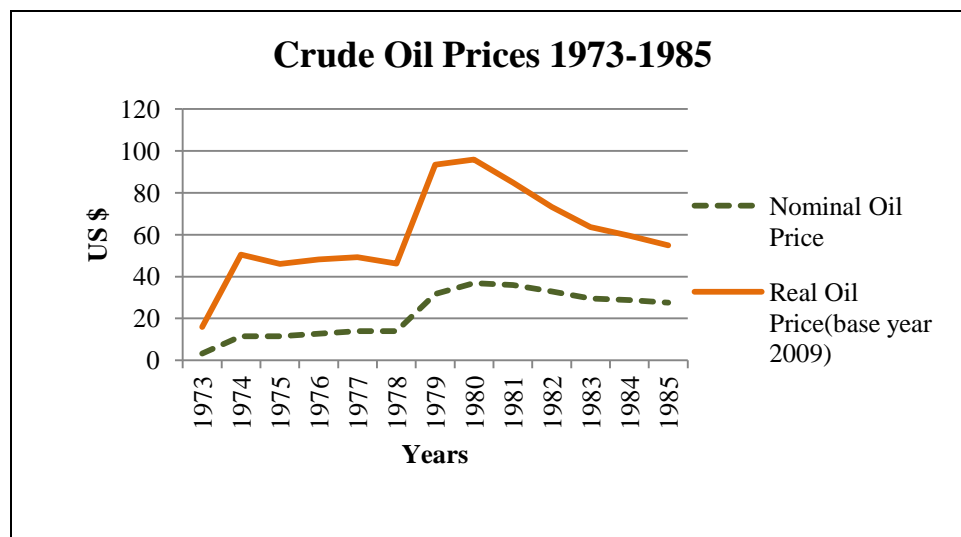


Figure 4.2: Real and nominal Crude Oil price 1973-1985
Source: BP-Statistical Review of World Energy, 2010

The second oil crisis in 1980 was caused by the events in Iran and Iraq and as a result world experienced a second round of oil price increases. The Iranian revolution resulted in the loss of 2 to 2.5 million barrels per day of oil production between November 1978 and June 1979. When the other OPEC nations, especially Saudi Arabia, declined to expand production to replace lost Iranian output, prices again exploded (Adelman, 2002). According to IEA (2004), these two events caused a fall in the economic growth of some oil importing countries.

The third period of examination 1986-1999, is characterized by the Iraq's invasion of Kuwait (Gulf War-Third oil shock) which causes an increase in oil prices. Kuwait

invasion by Iraq took place in 1989-1990. Observing figure 4.3 we can see clearly that the oil price shock in 1990 was not as intense as the previous oil shocks of 1973 and 1979. In that period prices still were more volatile than other commodities, but the fluctuations were far less than they had been since 1973 (Adelman, 2002). In the third period, 1986–1999, nominal crude oil prices seemed to have become stationary whereas real prices were trending downward (Krichene 2002).

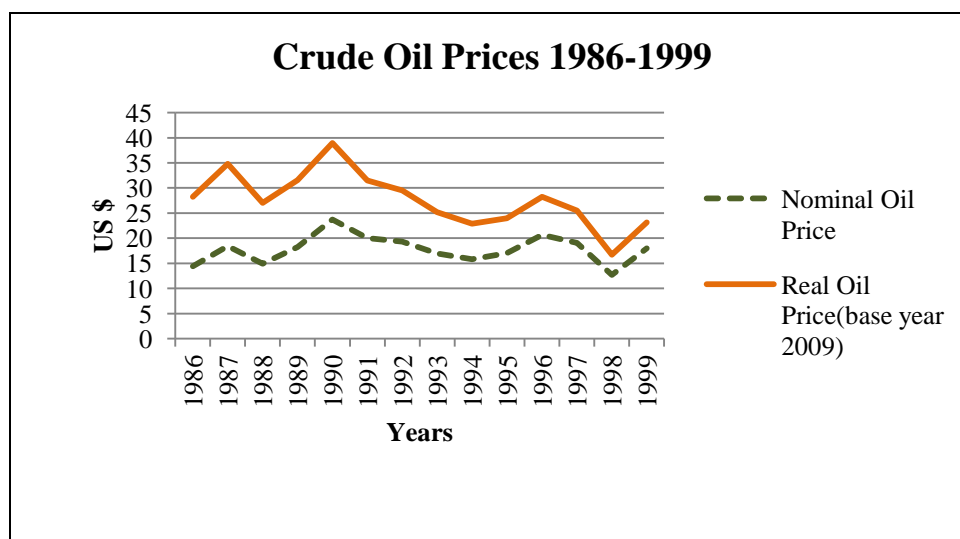
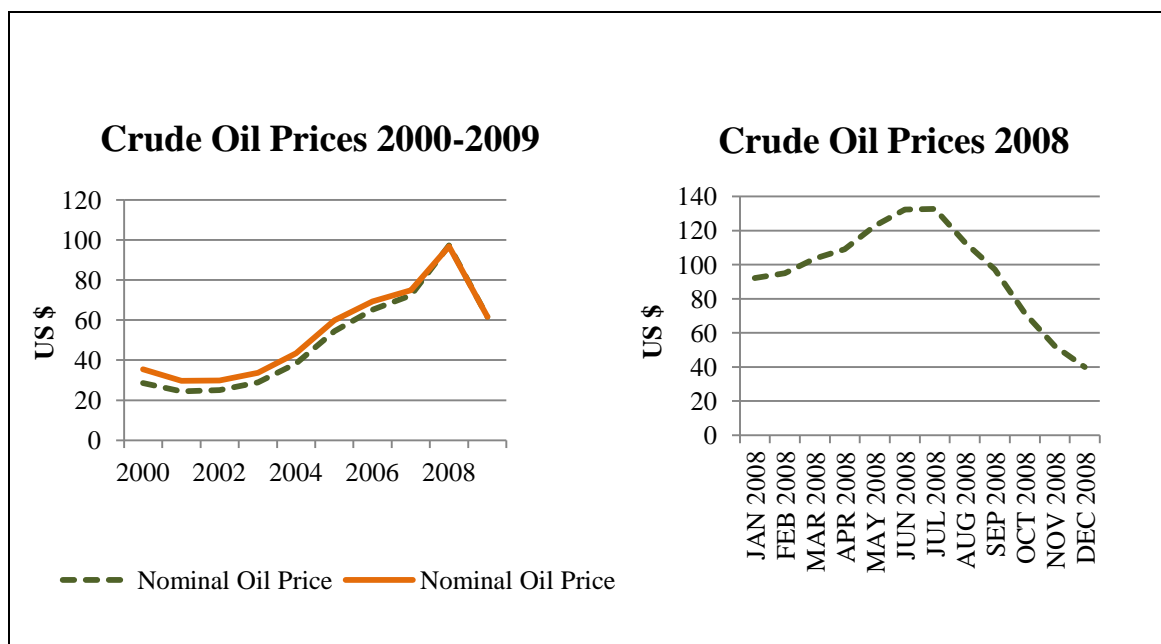


Figure 4.3: Real and nominal Crude Oil price 1986-1999

Source: BP-Statistical Review of World Energy, 2010

In the last period 2000-2009 crude oil prices increased gradually reaching a peak in 2008 of \$96.1 in nominal terms. Figure 4.4a indicates the increase in oil price both in nominal and real terms. A series of events led the price to increase since 2000. Some of these events is the invasion of Iraq in 2003 and the financial crisis in 2008. Unlike the historical oil price peaks of the last century, which were associated with stagflation crises, the macroeconomic impact of the most recent oil price upsurge was generally moderate until mid-2007 (Breitenfellner et al., 2009). High oil prices have an effect to the economies of oil-importing and oil-exporting countries (IEA, 2004).

Figure 4.4b indicates the oil prices during the year of 2008. Crude oil price was \$92.18 in January of 2008 and increased to an all time peak of \$132.72 (The fourth oil shock) in July of 2008. Hamilton (2009) refers to the possible factors that contributed to the oil price increases in 2008. These factors are the commodity price speculation, the strong world demand (especially from the side of China), time delays or geological limitations on increasing production and the OPEC monopoly pricing.



Figures 4.4a & 4.4b: Real & nominal Crude Oil Price (2000-2009 - 2008 Crude Oil price
Source: BP-Statistical Review of World Energy, 2010 - IEA

4.2 Countries' Energy Sector and Review of historic GDP/Oil Trends

This section presents statistical information about countries' energy sector and illustrates historical data on oil consumption per capita and real GDP per capita for each country.

4.2.1 Sweden

As reported by IEA (2008a) Sweden has made a really important progress during the last six years in implementing energy efficiency policies by increasing the use of renewable energy through the development of new technology and at the same time decreasing the use of oil. Specifically IEA (2008a), states that Sweden is one of the leading countries that use renewable energy. Sweden is the first country with the ambitious target of being an oil free society by the year 2020. Sweden's vision of a sustainable energy system implies phasing out oil and others fossil fuels in the long term (IEA, 2008a). For that reason the Swedish government applied in December of 2005 a commission to work on how Sweden could reduce its dependence on oil. As stated in Commission's report Sweden should reduce the oil dependence in transport and industry sector and phase out the use of oil for space heating. Its proposals,

however, were not politically binding and the current government has not supported them.

Figure 4.5 shows that the reliance of Sweden's energy mix upon oil reaches 29% (14.34 Million Tonnes of Oil Equivalent - Mtoe) of the total energy supply in 2008 which is below than the EU-27 average percent of 37%⁵. Nuclear power as well as renewable resources has the dominating position in the primary energy supply accounting for 32%. Solid fuels (mainly coal) and natural gas represent 5% and 2% respectively of the total primary energy supply. Sweden's total primary energy supply has the lowest share of fossil fuels (coal, petroleum, gas) within the IEA countries, around 35% in 2006 (IEA, 2008a). It is obvious that nuclear power and renewable resources plays a key role in Sweden's energy mix. IEA (2008a), states that Sweden has adequate renewable resources and use nuclear power in high level in order to reduce the use of oil.

Figure 4.6 illustrates Sweden's total final energy consumption by sector in 2008. Sweden's total final consumption of energy was 32.84 Mtoe. Industry is the largest energy consumer representing 37% (12.29 Mtoe) of the total energy supply followed by transport (28%) and households (20%). The last share in the total final energy consumption has the agriculture sector accounting only for 2%. According to Commission on Oil Independence (2006) the use of oil in transport sector for 2004 was 97% and the dominant area of use was the motor operation. For comparison the EU-27 average in 2008 was 27% for industry and 33% for transport (European Commission).

⁵ European Commission, Market Observatory for Energy, downloaded on 18/08/2011 by: http://ec.europa.eu/energy/observatory/index_en.htm

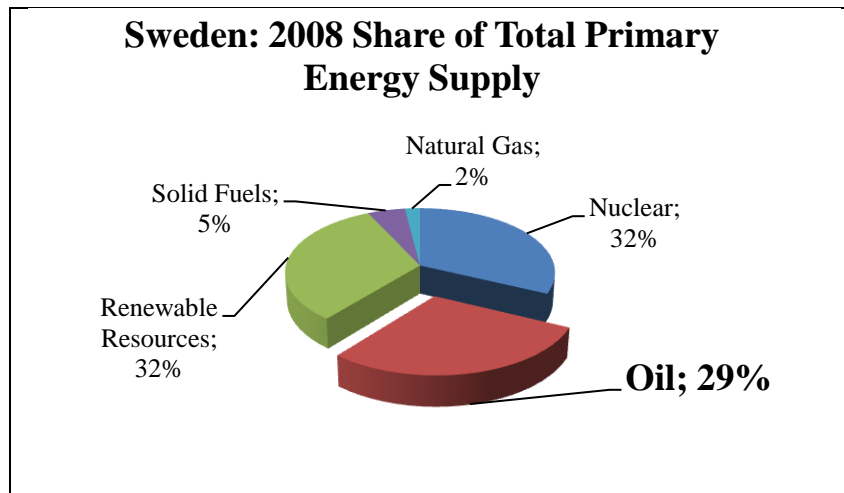


Figure 4.5: Sweden: Share of Total Primary Energy Supply in 2008
Source: BP, Statistical Review of World Energy, 2010

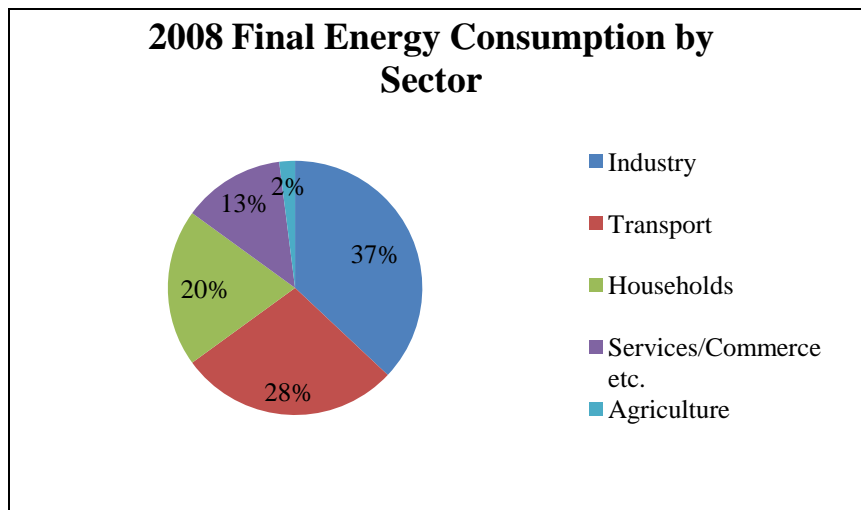


Figure 4.6: Sweden: Share of Total Final Energy Consumption by Sector in 2008
Source: IEA, <http://www.iea.org/stats/index.asp>

Sweden covers its needs for oil by imports as there is no domestic production of oil. The domestic production of energy consists mainly of nuclear power and renewable resources (European Commission). Crude oil imports in 2008 accounted for 21 million tonnes in total. From that amount, 34% came from Russia while only 9% of the crude oil imports stem from OPEC countries.

Figure 4.7 depicts the relationship between crude oil consumption and GDP. As can be seen oil consumption and real GDP per capita have been following different trends indicating a negative correlation. Oil consumption has been decreased throughout the last thirty years (1980-2009) and in the same time period the GDP recorded a significant increase. Specifically the average annual rate of change of oil consumption

per capita and real GDP per capita is -1.89 and 1.64 respectively. In the last time period of our analysis (2009) Swedish GDP and crude oil consumption fall by 5.98% and 5.65% respectively.

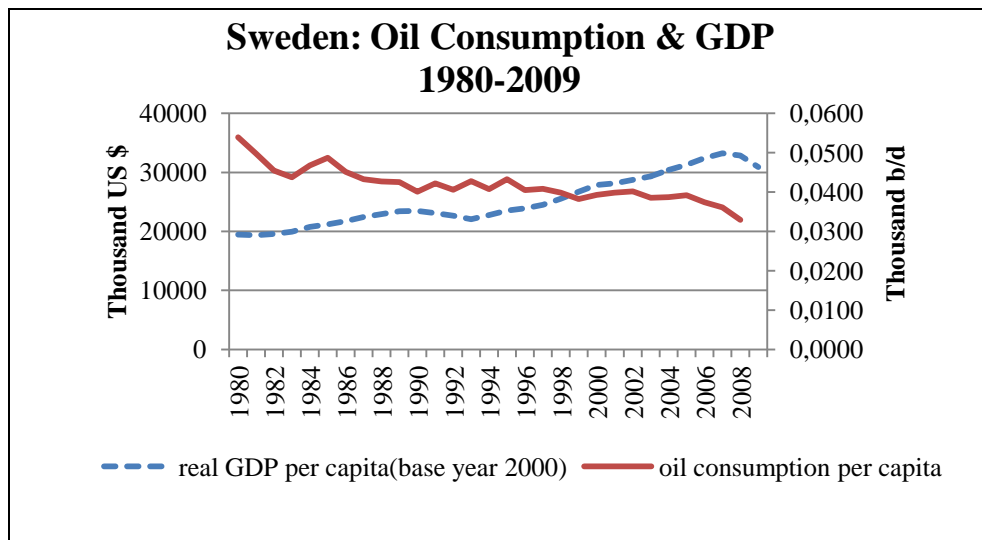


Figure 4.7: Sweden: Historical relationship between oil consumption and GDP
Source: BP, Statistical Review of World Energy, 2010 – World Bank

4.2.2 Denmark

Denmark has the vision of being fossil fuels independent by 2050. For that reason the Danish Government set a commission to make some strategies and a feasible plan on how Denmark can be fossil fuels-free in the long run. Europe and thus Denmark's security of supply as regards oil and gas in particular has been weakened in the long term because domestic reserves are being exhausted and because the remaining reserves are concentrated in relatively few countries and regions. Government's strategy to these challenges is that Denmark should become independent of fossil fuels (Energy Policy Statement, 2010).

Denmark is one of the largest producers of oil⁶ (BP, 2010) in the EU-27 and we can say that oil plays a key role in Denmark's energy mix. Figure 4.8 illustrates Denmark's primary energy supply in 2008. Oil is the major fuel accounting for 41% of the total energy supply. The second energy source is solid fuels (mainly hard coal) which represent 20% followed by natural gas (21%) and renewable resources (18%) such as wind power and biomass. The share of renewable energy in total supply is

⁶ Oil production includes crude oil, shale oil, oil sands and NGLs (the liquid content of natural gas where this is recovered separately).

much higher than the EU-27 average of 8%⁷. It is interesting that Denmark's energy supply does not base at all in nuclear power.

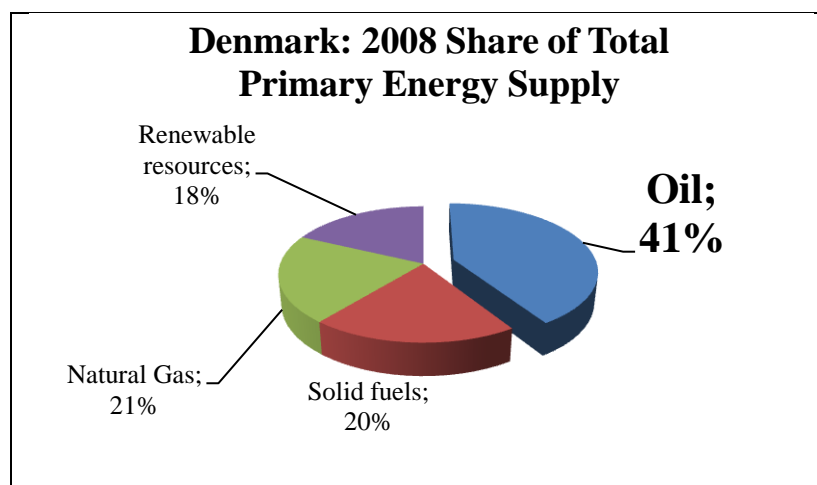


Figure 4.8: Denmark: Share of Total Primary Energy Supply in 2008
Source: BP, Statistical Review of World Energy, 2010

Danish Commission presented how Denmark's energy mix will change in 2050 if the targets for the fossil fuel-independency succeed. As stated in Danish Commission (2010) renewable resources such as biomass and wind will be the primary energy sources. Specifically, wind power will double in 2050 from the current level and biomass will play a pivotal role.

It is clear from figure 4.9 that transport and households are the most energy consuming sector in Denmark in 2008 representing 34% and 29% respectively of final energy consumption.

Denmark meets its demand for crude oil primarily by domestic production. It is one of the few net energy exporters among EU Member States (IEA, 2006). Denmark is one of the largest oil producers in the European Union with 265 thousand barrels/day in 2009 (BP, 2010). As reported in IEA (2006), oil accounted for 54% of the total primary energy production followed by natural gas (34%) and renewable resources (12%).

⁷ European Commission, Market Observatory for Energy, downloaded on 18/08/2011 by: http://ec.europa.eu/energy/observatory/index_en.htm

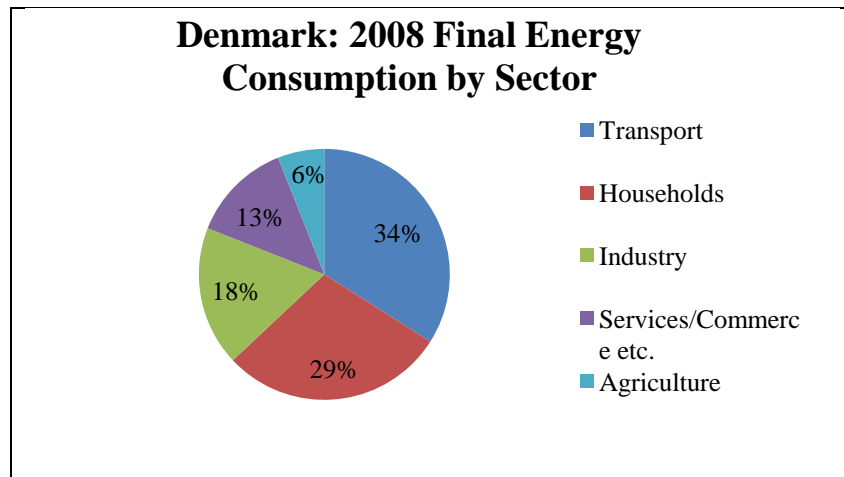


Figure 4.9: Denmark: Share of Total Final Energy Consumption by Sector in 2008
Source: IEA, <http://www.iea.org/stats/index.asp>

Oil consumption per capita and real GDP per capita in Denmark has been following different trends. This is obvious in figure 4.10 which can be seen that real GDP per capita and oil consumption per capita are negative correlated. In 2009 real GDP per capita was \$30,548 and oil consumption per capita accounted for 0.03224 thousand barrels per day.

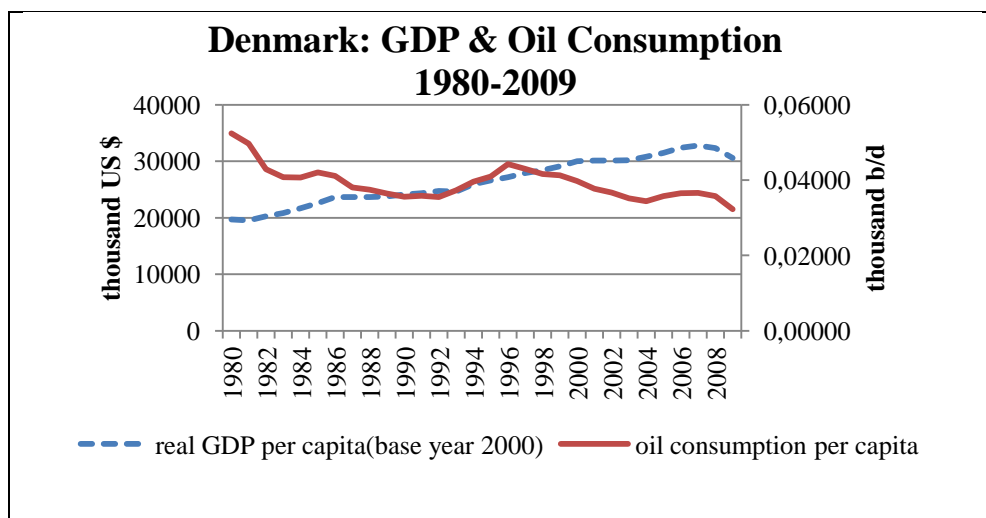


Figure 4.10: Denmark: Historical relationship between oil consumption and GDP
Source: BP, Statistical Review of World Energy, 2010 – World Bank

4.2.3 Spain

Spain's energy mix based primarily on oil and natural gas. Spain is a country without domestic crude oil and natural gas production and strongly depends in energy imports. However, it has developed the production of nuclear power as well as the use of

renewable resources. Spanish government supports renewable energy growth through investment subsidies and tax incentives for biofuels in transport.

Spain's total primary energy supply accounted for 138 Mtoe in 2008, increased from 1990 by 53% (IEA, 2009b). It is notable that Spain's total primary energy supply has grown consistently since 1973, increasing by a compound average annual growth rate of 2.6% (IEA, 2009b). Figure 4.11 shows that oil is the dominant source of energy provided 47% of total energy supply followed by natural gas which has a significant share of 24%. Nuclear power and solid fuels represent 11% and 10% respectively. The share of renewable resources (8%) has grown considerably over the last decade, due to the measures of Spanish government to promote wind and photovoltaics (IEA, 2009b). Moreover as stated in IEA (2009b) Spain has become the second largest country in the world in terms of installed wind capacity.

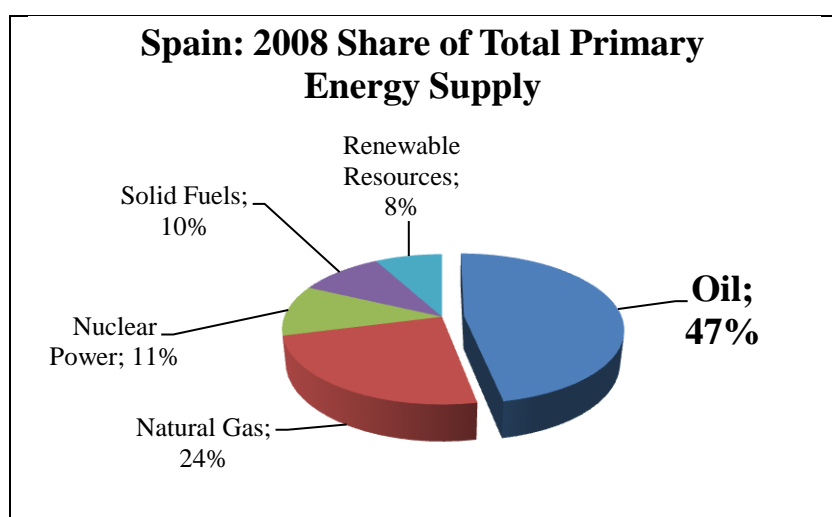


Figure 4.11: Spain: Share of Total Primary Energy Supply in 2008
Source: BP, Statistical Review of World Energy, 2010

Final Energy Consumption in Spain has increased significantly by 66% since 1990 (BP, 2010). Transport and Industry are by far the more energy consuming sector accounted for 42% and 28%, respectively in 2008. As reported by IEA (2009b) the share of transport has remained constant over the past twenty years and in the same time period the share of industry decreased from more than 40%. Oil is used mainly in transport and industrial sector representing 58% and 20% respectively of the total oil consumption (IEA, 2009b).

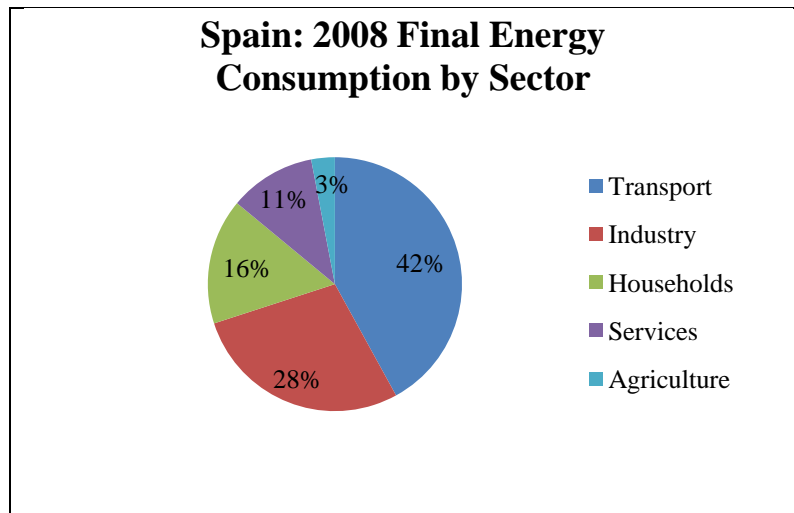


Figure 4.12: Spain: Share of Total Final Energy Consumption by Sector in 2008
Source: IEA, <http://www.iea.org/stats/index.asp>

Spain has no domestic oil and natural gas production. Its energy production is based on nuclear power which accounted for 51% of the total, while renewable resources representing 35%. The share of renewable sources has increased substantially since 1990 being far above the EU-27 average of 12%⁸. Finally the share of solid fuels (mainly coal and lignite) accounted for 14%. Spain covers its need for crude oil exclusively by imports. It has very limited oil production, which stood at 3 thousand barrels/day in 2008 (IEA, 2009b). According to IEA (2009b) OPEC is the mainly foreign supplier of crude oil as 55% of the total imports came from OPEC countries. Furthermore, significant amounts of oil are imported from Russia and Mexico.

Figure 4.13 shows the evolution of real GDP per capita and oil consumption per capita since 1980. As can be seen both variables follow a similar upward trend indicating that they are positive correlated. In 2009 real GDP per capita was \$15,534 while oil consumption per capita accounted for 0.03297 thousand barrels/day.

⁸ European Commission, Market Observatory for Energy, downloaded on 18/08/2011 by: http://ec.europa.eu/energy/observatory/index_en.htm

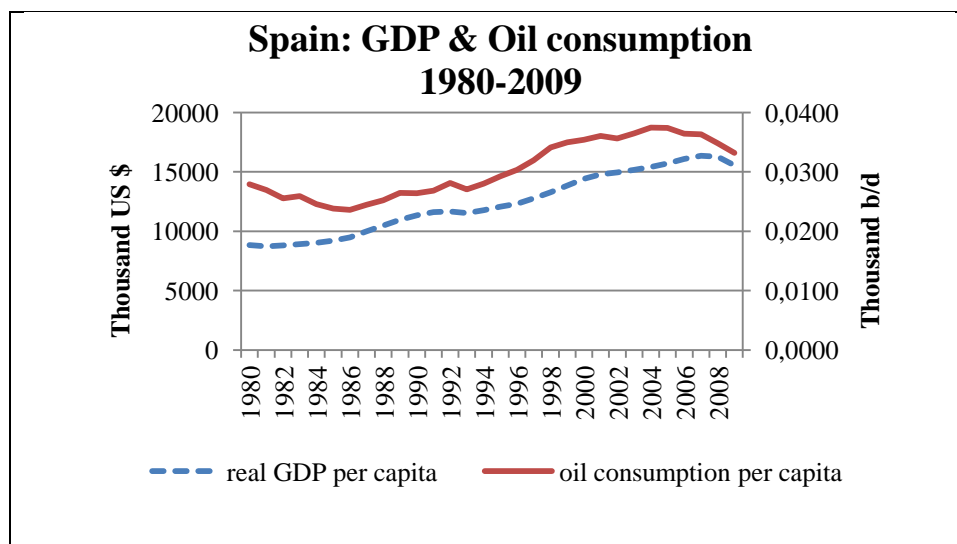


Figure 4.13: Spain: Historical relationship between oil consumption and GDP
Source: BP, Statistical Review of World Energy, 2010 – World Bank

4.2.4. Portugal

Portugal covers its energy needs mainly by using oil. Historically, Portugal was highly dependent on imported fossil fuels (IEA, 2009a). However, the recent years Portugal has invested in renewable energy and considered as a leader in the use of renewable energy resources. Renewable energy policy, therefore, is an important instrument for achieving broader policy goals of energy security, sustainability and competitiveness (IEA, 2009a).

The strong dependence of Portuguese energy mix on oil and the development of renewable energy can be seen clearly in figure 4.14. Primary energy supply in Portugal has increased significantly since 1990 by 55% (IEA, 2009a). The share of oil in primary energy supply accounted for 55% in 2008, significantly higher than the EU-27 average share of 37% in the same year⁹. As reported in IEA (2009a) oil has been the mainly source of energy over the past forty years, but the share of oil in Portugal's energy mix has reduced from 75.5% in 1973 to 64.3% in 2001 and finally to 55% in 2008. Renewable resources have a quite significant share of 18% in 2008 which is quite higher from the corresponding EU-27 average share of 8%⁹. Natural gas accounted for 17% of the total primary energy supply followed by solid fuels

⁹ European Commission, Market Observatory for Energy, downloaded on 18/08/2011 by: http://ec.europa.eu/energy/observatory/index_en.htm

(mainly coal) which represent 10%. It is notable that Portuguese energy mix does not base at all in nuclear power.

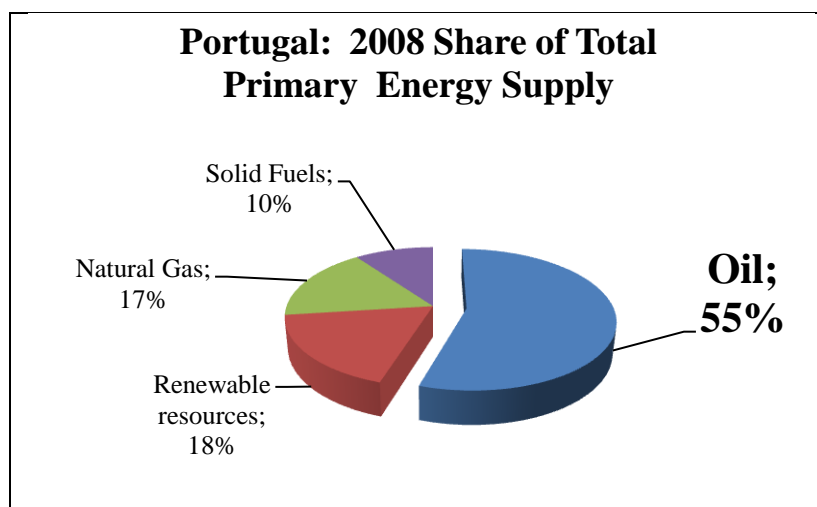


Figure 4.14: Portugal: Share of Total Primary Energy Supply in 2008
Source: BP, Statistical Review of World Energy, 2010

Portugal's total final consumption of energy was 20.79 Mtoe in 2008, which represents an increase of 3.3% above the 2007 level of 20.10 Mtoe (BP, 2010). In 2008 transport and industry were the largest energy consuming sector representing 40% and 30% respectively of the total final energy consumption followed by households (17%) and agriculture (11%). 61% of the total consumed energy comes from oil, while 20% is electricity and 12% renewable energy.

Portugal is an exclusive producer of renewable energy resources primarily hydropower and biomass (IEA, 2009a). As there is no crude oil and coal production, Portugal meets its demand for fossil fuels by foreign suppliers. Portugal imports crude oil mainly from OPEC countries and Brazil. In 2008, 72% of the total imported crude oil supplied by OPEC countries and only 11% imported by Brazil¹⁰. Other foreign suppliers of crude oil are Kazakhstan and Norway. Except for oil, Portugal imports significant amounts of natural gas and coal. Gas is imported from Nigeria and Algeria while coal mainly originates from Colombia and South Africa

¹⁰ European Commission, Market Observatory for Energy, downloaded on 18/08/2011 by: http://ec.europa.eu/energy/observatory/index_en.htm

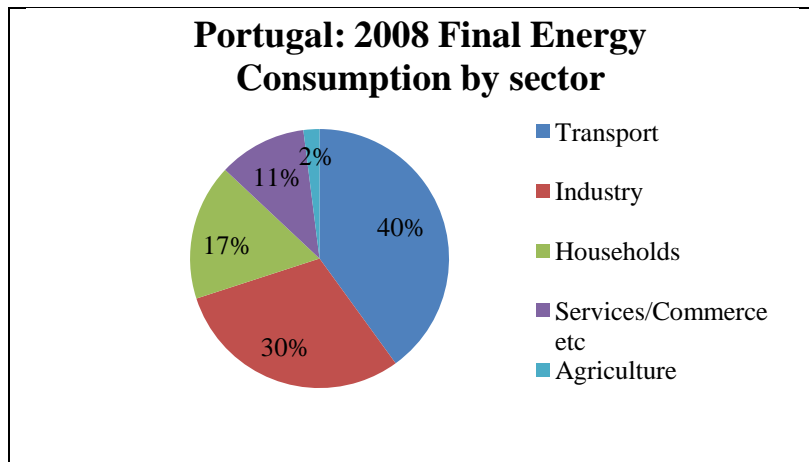


Figure 4.15: Portugal: Share of Total Final Energy Consumption by Sector in 2008
Source: IEA, <http://www.iea.org/stats/index.asp>

It is obvious that Portuguese energy mix, as well as Spanish, is heavily reliant upon crude oil. The Portuguese government expects to gradually decrease the share of oil and coal in energy supply to 43.9% and 6.7% respectively in 2020 (IEA, 2009a) and at the same time period to increase the portion of renewable energy resources (mainly the hydropower).

As can be seen in figure 4.16, real GDP per capita and oil consumption per capita in Portugal follow a very similar upward trend, indicating that these two variables are positively correlated. Oil consumption per capita was 0.0247 thousand barrels per day in 2009 and real GDP per capita accounted for \$11,588 in the same time period.

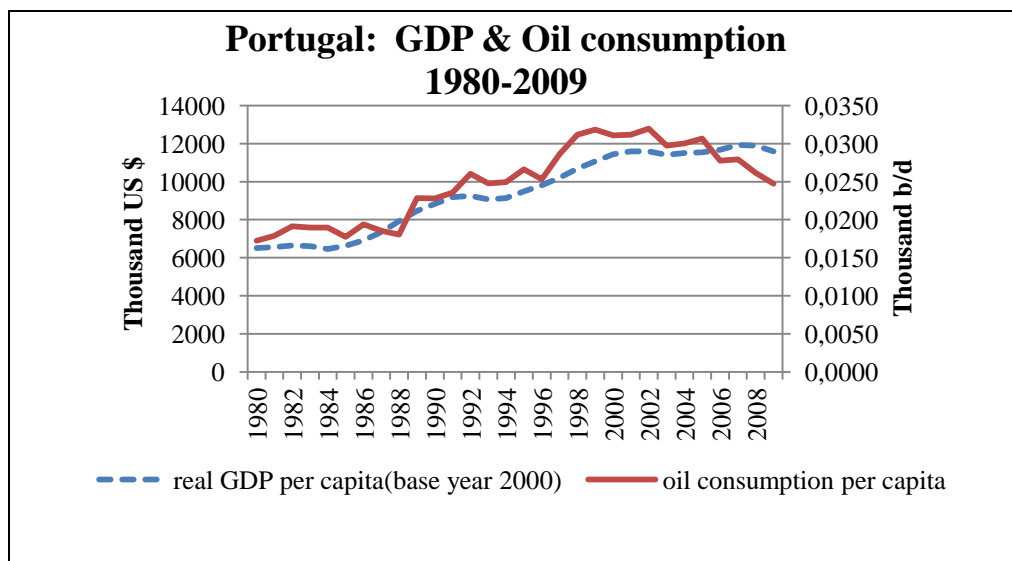


Figure 4.16: Portugal: Historical relationship between oil consumption and GDP
Source: BP, Statistical Review of World Energy, 2010 – World Bank

4.2.5 Turkey

Although Turkey is a new developed country it has made a remarkable progress on energy policy over the recent years. According to IEA (2009c) Turkey should continue reforming its energy market in order to attract investments. Turkey is heavily reliant on imports for covering its energy demand. For that reason, Turkey is making efforts to diversify supplies to reduce supply risks, including diversifying import sources and developing oil projects abroad (Altinay, 2007).

Total primary energy supply accounted for 99 Mtoe in 2008 increasing by 87% since 1990 (BP, 2010). Figure 4.17 illustrates the share of total primary energy supply in 2008. Natural gas has a dominant share of 31% recording a significant increase over the past years. Natural gas in 1990 was representing only 6% of the total primary energy supply (BP, 2010). Oil as well as solid fuels provided together 60% of the total primary energy supply. The reduce of the share of oil in total primary energy supply from 46% (BP, 2010) to 30% in 2008 stem from the expansion of use of natural gas. Renewable resources represent only 9% and Turkish government is making strategies for the efficient use of solar and geothermal energy to further diversify its power generating capacity (IEA, 2009c).

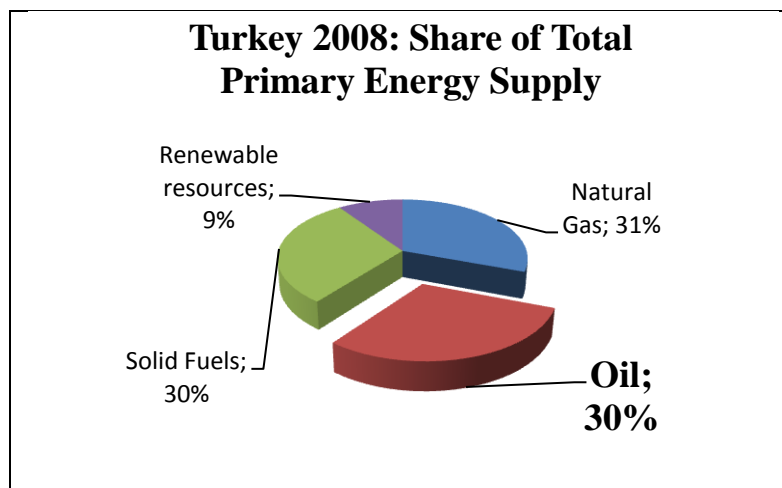


Figure 4.17: Turkey: Share of Total Primary Energy Supply in 2008
Source: BP, Statistical Review of World Energy, 2010

The residential sector was the most energy-consuming one in Turkey in 2008: it recorded a 33% share of total final energy consumption. Industry and Transport are also highly energy-users representing respectively 26% and 22% of the total energy consumption. As reported by IEA (2009c) total final consumption is expected to be

doubled to 163 Mtoe in 2020, with most growing stemming from the use of coal, oil and electricity.

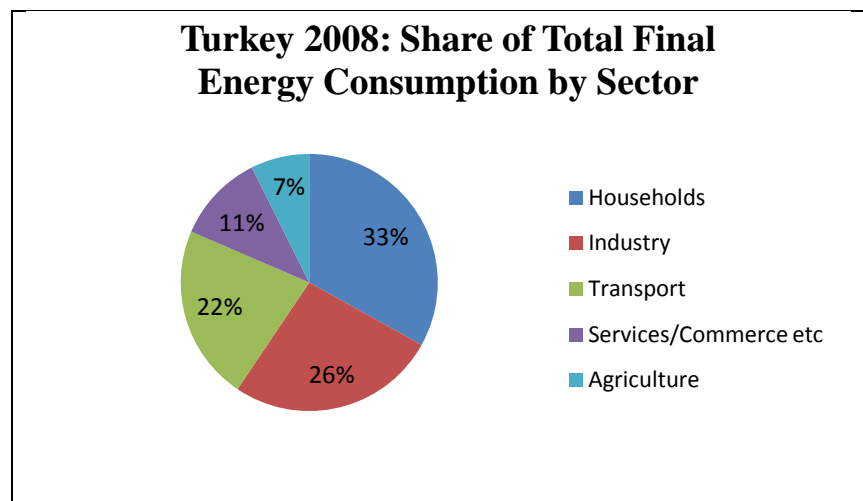


Figure 4.18: Turkey: Share of Total Final Energy Consumption by Sector in 2008
Source: IEA, <http://www.iea.org/stats/index.asp>

Turkey covers its needs for crude oil mainly by imports. Specifically, Turkey imports 91% of the total crude oil demand while 9% covered by indigenous production (IEA, 2009c). The crude oil foreign suppliers of Turkey are primarily the Middle Eastern countries such as Saudi Arabia, Iran and Iraq, and North African countries such as Libya, and Egypt (Altinay, 2007). Turkey has remarkable coal domestic production. According to IEA (2009c), Turkey has large coal reserves and aims to multiply their use over the next decade for electricity production.

Figure 4.19 shows the historical evolution of real GDP per capita and oil consumption per capita since 1980. As can be seen real GDP per capita has increased at an exponential rate recording a 2.45% average annual rate of growth for the time period under investigation. Regarding oil use in Turkey, oil consumption per capita has increasing by 1.04% in average. As reported in IEA (2009c), energy use in Turkey is expected to roughly double over the next decade due its rapidly economic growth.

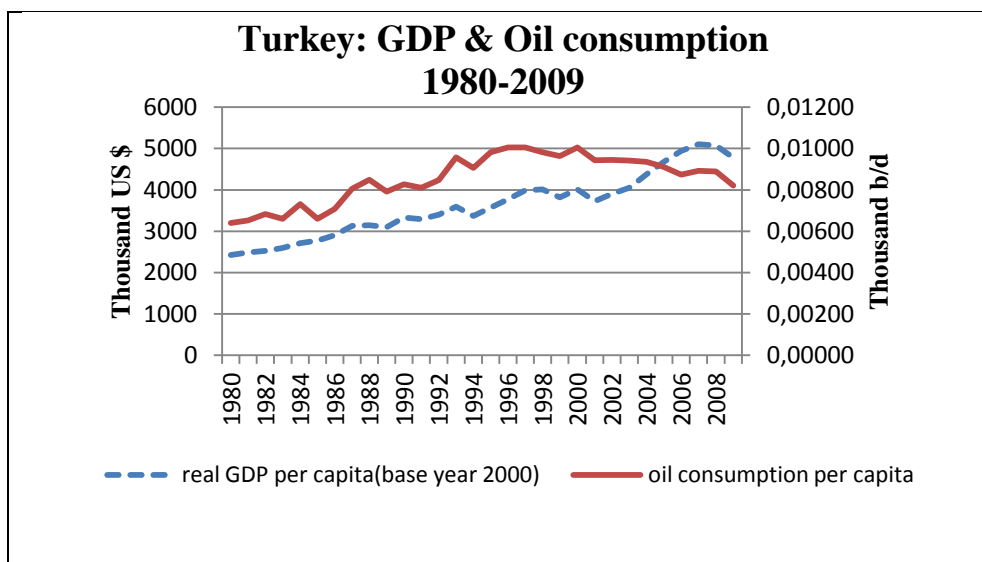


Figure 4.19: Turkey: Historical relationship between oil consumption and GDP
Source: BP, Statistical Review of World Energy, 2010 – World Bank

4.2.6 Finland

Finland is a country with a low share of oil in its energy mix and a significant share of renewable energy resources. Due to a lack of energy resources production, Finland is heavily reliant upon energy imports.

Figure 4.20 shows that Finish energy mix is well diversified as it consists of five fuels: oil, renewable, nuclear power, natural gas and solid fuels. Specifically, the share of oil in total primary energy supply accounted for 31% in 2008 much lower of the EU-27 average of 37%. The share (26%) of renewable resources (mainly biomass) is quite higher than the EU-27 average of 8%¹¹. Nuclear power and solid fuels accounted for 17% and 15% respectively while natural gas contributes only 11% to the primary energy supply although the fact that supply of natural gas has shown the largest increase of 75% over the period 1990-2004 (IEA, 2007a).

¹¹ European Commission, Market Observatory for Energy, downloaded on 18/08/2011 by: http://ec.europa.eu/energy/observatory/index_en.htm

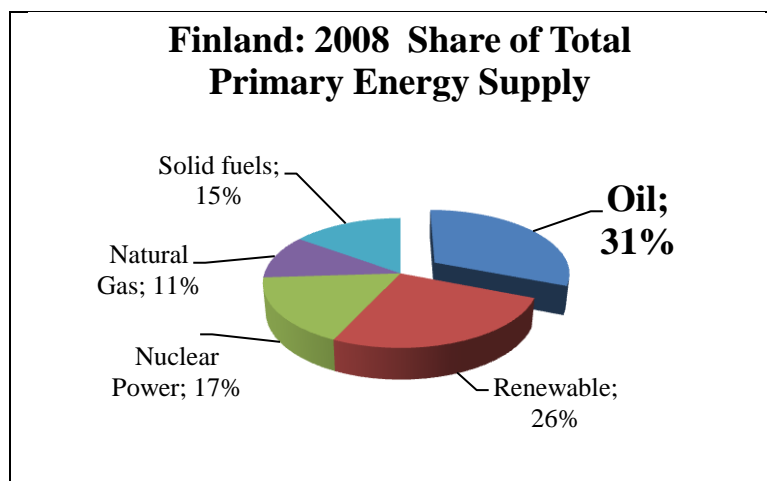


Figure 4.20: Finland: Share of Total Primary Energy Supply in 2008

Source: BP, Statistical Review of World Energy, 2010

In 2008 the total final consumption of energy accounted for 25.88 Mtoe. Industry is by far the more consuming energy sector in Finland represented almost the half (49%) of the total final consumption followed by transport (19%) and households (19%).

Finland meets its demand for crude oil exclusively by foreign suppliers as there is no domestic crude oil exploration or production of oil. Russia is the mainly supplier of crude oil. Other countries that supply Finland by oil are Norway (10%), United Kingdom (3%) and Denmark (2%). Moreover Finland has no domestic natural gas and coal production and consequently imports those two kinds of fossil fuels by Russia. According to IEA (2007a), although that Finland has mainly import connections with Russia, the construction of a connection to Europe is a high priority for the Finish government. Renewable resources is the dominant source of energy production represents 55% of the total domestic production, followed by nuclear power which has an increasing rate over recent years¹². Total domestic production exhibited an increase of 36% since 1990 (IEA, 2007a).

¹² European Commission, Market Observatory for Energy, downloaded on 18/08/2011 by: http://ec.europa.eu/energy/observatory/index_en.htm

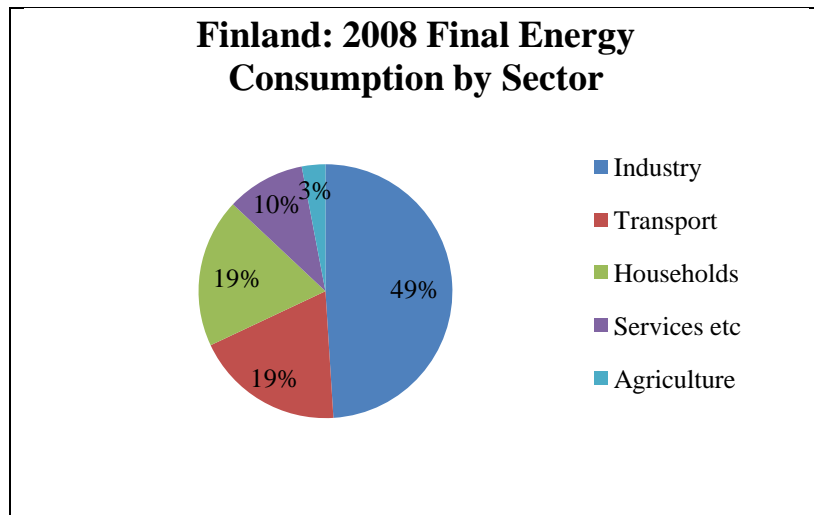


Figure 4.21: Finland: Share of Total Final Energy Consumption by Sector in 2008
Source: IEA, <http://www.iea.org/stats/index.asp>

Oil consumption in Finland follows a relatively constant trend over the years. During the time period under investigation 1980–2009, oil consumption per capita decreased by 0.95% reaching 0.0392 thousand barrels/day in 2009 (BP, 2010). So it seems that oil consumption is constant in the long run. On the other hand, in the same time period Finland had a constant positive economic growth. In 2009 the real GDP per capita accounted for \$26,496.

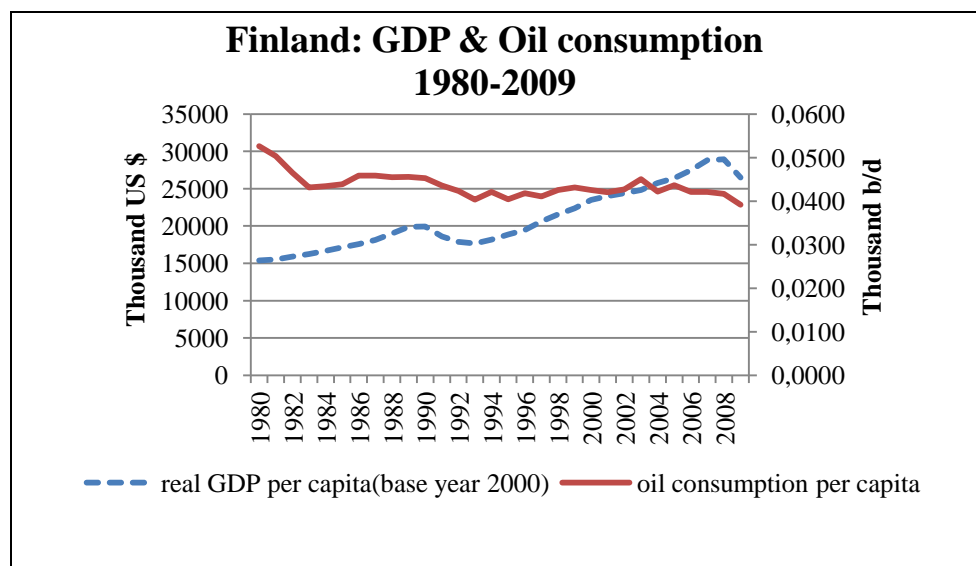


Figure 4.22: Finland: Historical relationship between oil consumption and GDP
Source: BP, Statistical Review of World Energy, 2010 – World Bank

4.2.7 Italy

The Italian government has made substantial progress in energy efficient recognizing the need to diversify its energy supply portfolio to reduce its heavy dependence on fossil fuels (IEA, 2009d). Italy has a limited domestic energy production without nuclear power plants and consequently is heavily dependent on energy imports. It is notable that Italian government announced in 2008 its intention to start building a new nuclear power plant by 2013 (IEA, 2009d).

Italy's primary energy supply accounted for almost 178 Mtoe in 2008 indicating that Italy is among Europe's largest energy consumers (BP, 2010). As can be seen from figure 4.23 oil and natural gas accounted for more than 80% of the total primary energy supply. However, oil demand has declined by 18% percent over the past eighteen years dropping from 90.1 million tonnes in 1990 to 77.8 million tonnes in 2008 (IEA, 2009d). Solid fuels and renewable resources represent 9% and 8% of the total primary energy supply. Renewable resources have increased since 2000 when they represented 5.9% of total primary energy supply (BP, 2010). According to (IEA, 2009d), renewable energy comes mainly from hydropower and geothermal sources.

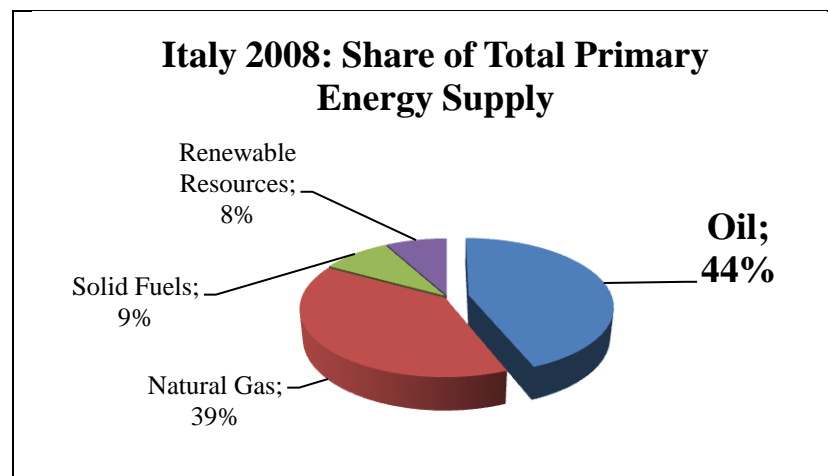


Figure 4.23: Italy: Share of Total Primary Energy Supply in 2008
Source: BP, Statistical Review of World Energy, 2010

Transport and industry are the most energy-consuming sector in 2008 accounted for 34% and 29% respectively of the total final energy consumption followed by households and services/commerce.

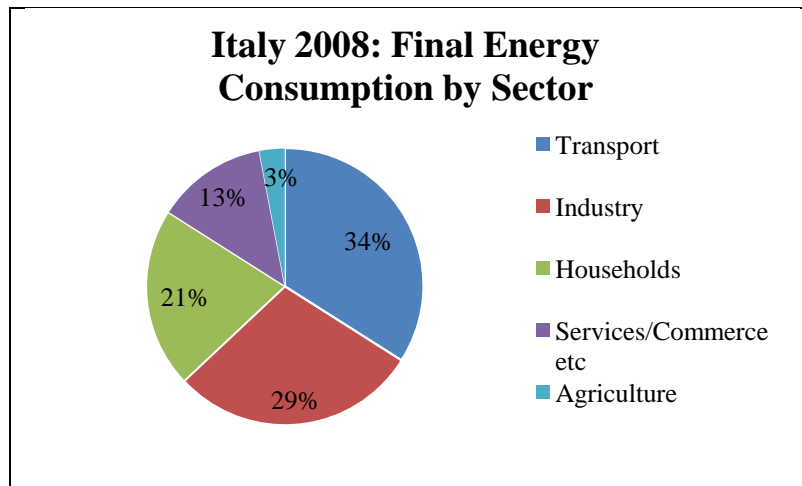


Figure 4.24: Italy: Share of Total Final Energy Consumption by Sector in 2008
Source: IEA, <http://www.iea.org/stats/index.asp>

Italy has indigenous production of natural gas and oil which represents 28% and 23% respectively of the total primary energy domestic production¹³. Due to the limited production of crude oil, Italy covers its crude oil need by imports. OPEC countries are the major suppliers of crude oil with Libya being the dominant source of oil (IEA, 2009d). Energy produced by renewable resources (geothermal, hydropower and wind power) has grown by 87% over the period 1990-2008 (IEA, 2009d) represented 49% of the total primary energy production¹³.

Oil consumption per capita in Italy under the investigation time period 1980-2009 has followed a relatively constant growth while for the same time period GDP per capita has significantly increased indicating that Italy exhibits a constant positive economic growth. It is notable that the past ten years oil consumption per capita has been steadily decreased, reaching 0.02595 thousand barrels/day in 2009 (BP, 2010). The average annual rate of change of oil consumption per capita is -0.91% while the associated rate of real GDP per capita accounts for 1.21%.

¹³ European Commission, Market Observatory for Energy, downloaded on 18/08/2011 by: http://ec.europa.eu/energy/observatory/index_en.htm

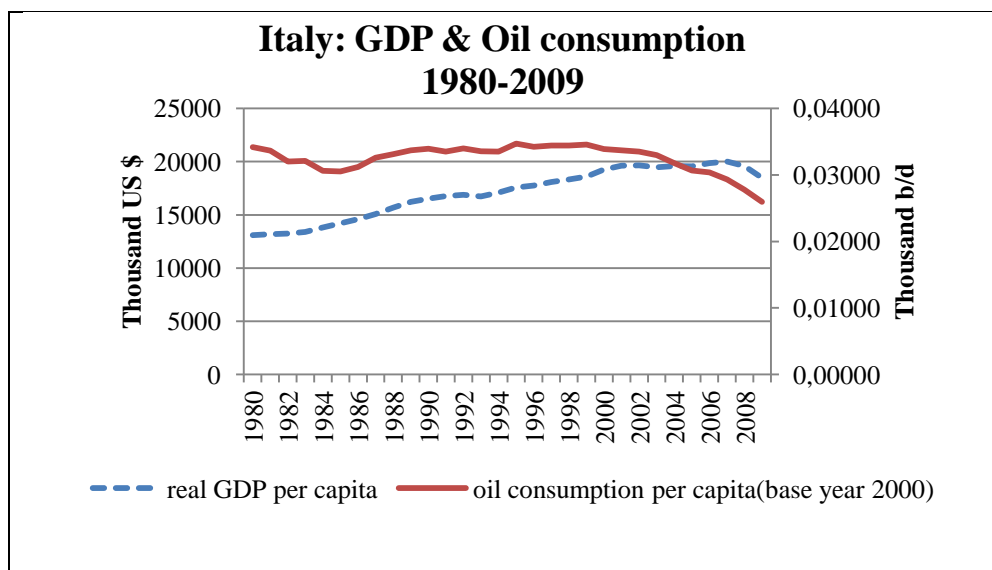


Figure 4.25: Italy: Historical relationship between oil consumption and GDP
Source: BP, Statistical Review of World Energy, 2010 – World Bank

4.2.8 Germany

Germany is the biggest country in European Union in terms of population and GDP. Moreover, its economy was the third largest in OECD countries and the fifth-largest globally in 2009. Its population accounts for almost 82 million people and its GDP accounted for 3,330 billion US dollars in 2009¹⁴. Furthermore, Germany is the first oil, coal and gas consuming-country in Europe in 2009, representing 2.9%, 2.9% and 2.2% respectively of the global oil consumption (BP, 2010). Germany has a strategic position within Europe and its government policy affect not only Europe but also the world.

Germany's energy supply accounted for 335 Mtoe in 2008. Its energy mix is quite well diversified consists of five different fuels. As figure 4.26 shows, oil has the largest share of total primary energy supply (34%) followed by solid fuels (24%) and natural gas (22%). The share of natural gas in energy mix recorded a significant increase since 1985 where gas accounted for 13% (IEA, 2010c). Nuclear power represents 11% of the total energy mix and renewable energy (biomass, solar, wind and geothermal) follows with a share of 9%.

¹⁴ Word Bank, The World DataBank, downloaded on 18/08/2011 by:
<http://databank.worldbank.org/ddp/home.do?Step=1&id=4>

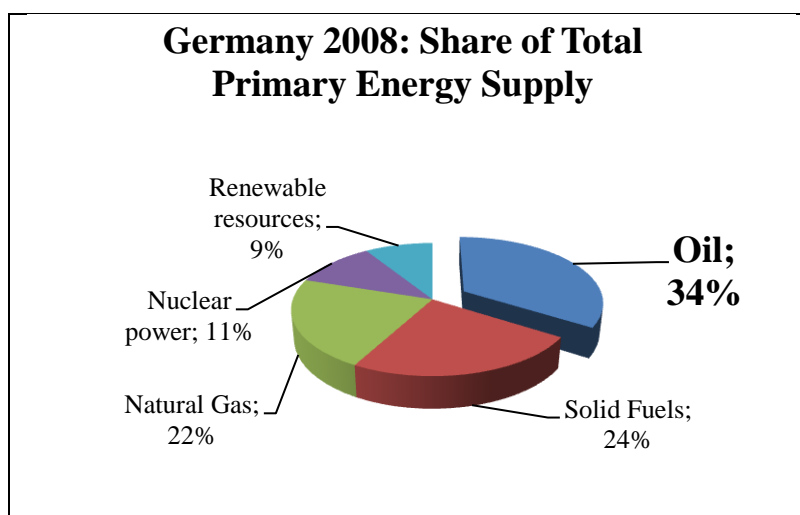


Figure 4.26: Germany: Share of Total Primary Energy Supply in 2008
Source: BP, Statistical Review of World Energy, 2010

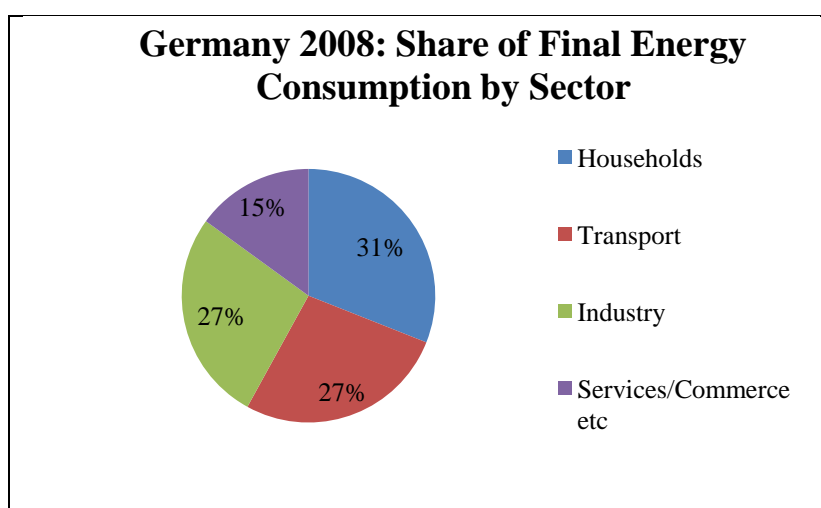


Figure 4.27: Germany: Share of Total Final Energy Consumption by Sector in 2008
Source: IEA, <http://www.iea.org/stats/index.asp>

Total Final Energy Consumption in Germany was 235 Mtoe in 2008 with residential sector having the largest share (31%). Transportation and industrial sector consume also remarkable amounts of energy followed by services and commerce

Germany meets its need for crude oil mainly by foreign suppliers. Crude oil imported from Former Soviet Union, Netherlands and Norway (IEA, 2007b). Germany is the second largest producer of coal and nuclear energy in European Union (BP, 2010). Although, Germany produces significant amount of nuclear energy, the government decided to steadily phase out nuclear power. That decision may lead to remarkable increases of lignite, hard coal, and gas fired power plants (IEA, 2007b).

Figure 4.28 illustrates the real GDP per capita trend compared to oil consumption per capita evolution since 1980. Oil consumption per capita has followed a substantial constant growth over the years recording an average annual growth rate of -0.87%. On the other hand real GDP per capita has tremendously increased since 1980. It is notable that industrial sector which plays a key role in country's economic growth, compared to many modern economies, contributing about one-quarter of gross domestic product (IEA, 2007b). The average annual growth rate of real GDP per capita over the period 1980-2009 is 1.56%.

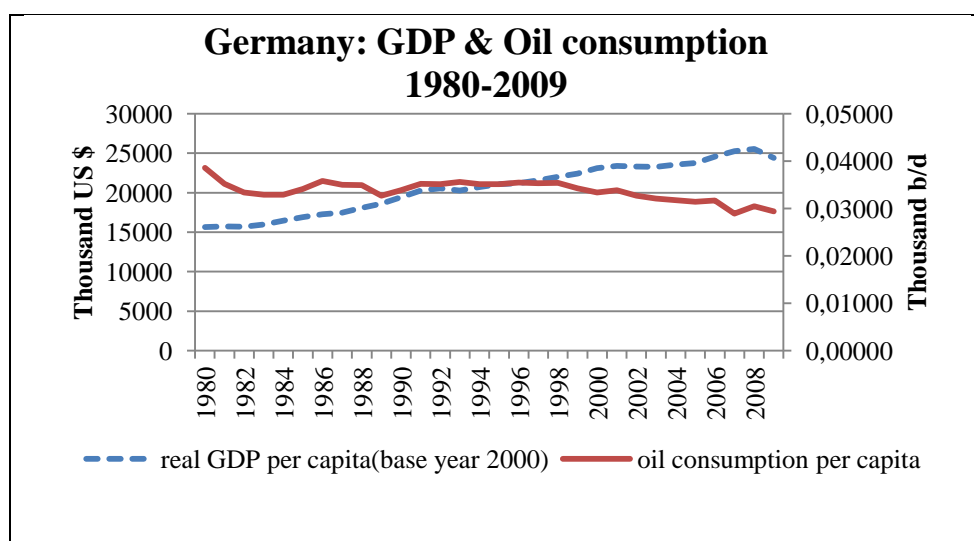


Figure 4.28: Germany: Historical relationship between oil consumption and GDP
Source: BP, Statistical Review of World Energy, 2010 – World Bank

4.2.9 United States of America

USA is a leader country in fossil fuels production and consumption. USA is the largest oil and gas-using country, globally consuming 1868 barrels/day and 589 Mtoe respectively in 2009 (BP, 2010). It is the third largest crude oil producer after Russian Federation and Saudi Arabia representing 8.5% of the world total oil production in 2009 (BP, 2010). Moreover, United States produces and consumes significant amounts of coal. As stated in EIA¹⁵, USA has produced so far more crude oil cumulatively than any other country and is the oldest major world oil producer. According to IEA (2007c), USA has made a remarkable progress the past years in energy policy by investing in research and development for the efficient use of

¹⁵ U.S Energy Information Administration (EIA), Oil Market Basics, downloaded on 18/08/2011 by: http://www.eia.gov/pub/oil_gas/petroleum/analysis_publications/oil_market_basics/default.htm

renewable energy such as solar photovoltaics and the implementation of next generation nuclear plants.

As can be seen in figure 4.29 crude oil has a dominant position in country's energy mix accounting for 38% of total primary energy supply in 2008. The share of oil in energy mix is quite high compare to other IEA member countries and will continue to grow (IEA, 2007c). Solid fuels (mainly coal) provided for 24% of the total supply followed by natural gas (23%), nuclear power (9%) and renewable resources (5%). Renewable energy has a relatively small role in country's energy mix increased only by 2% since 1990 (IEA, 2010c).

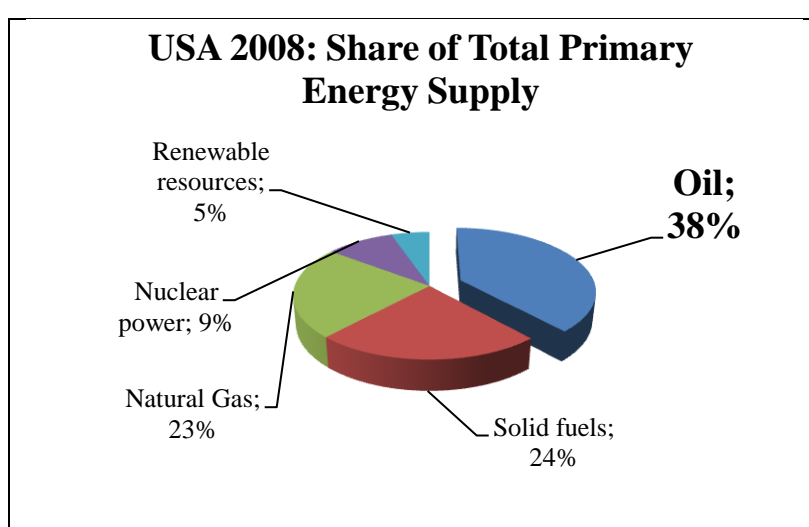


Figure 4.29: USA: Share of Total Primary Energy Supply in 2008
Source: BP, Statistical Review of World Energy, 2010

Transport is the largest crude oil-consuming sector, representing 49% of the total final energy consumption in 2008 followed by industrial (21%) and residential (19%) sectors. Commercial and services sector accounts for 15% of the total final energy consumption while agricultural sector represents only 1% in total.

Although, USA has a significant crude oil production, the country experiences a high demand for oil and consequently is becoming heavily reliant upon crude oil imports over the past years According to BP (2010) crude oil imports in 2008 were 8,893 barrels per day. Except for crude oil production, United States of America has significant recoverable reserves of coal representing 27% of the global total coal reserves (IEA, 2007c).

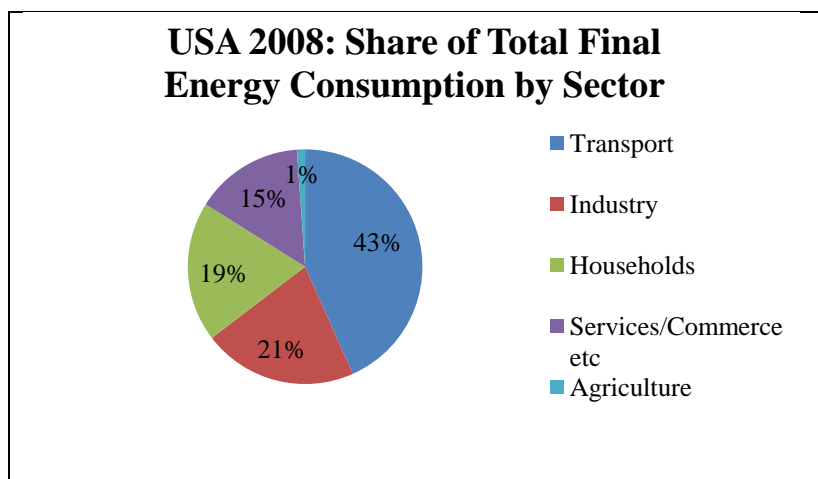


Figure 4.30: USA: Share of Total Final Energy Consumption by Sector in 2008

Source: IEA, <http://www.iea.org/stats/index.asp>

USA has experienced a strong economic growth in years under investigation (1980-2009). Real GDP per capita grew from \$22,630 in 1980 to \$37,016 in 2009 recording a remarkable average annual growth of 1.73%. At the same time period, oil consumption per capita has a relatively constant growth recording an average annual growth of -0.67%. As stated in IEA (2007c), strong economic performance has an effect on oil consumption by stimulating crude oil demand and supply.

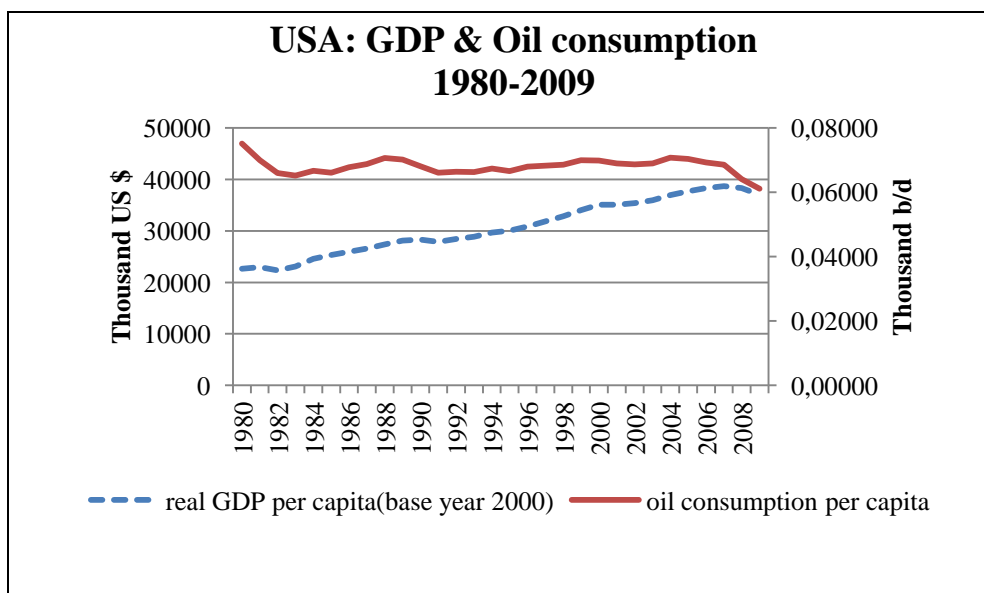


Figure 4.31: USA: Historical relationship between oil consumption and GDP

Source: BP, Statistical Review of World Energy, 2010 – World Bank

4.2.10 Japan

Japan is the second (USA is the first) largest economy among IEA member countries and the third globally after USA and China. Japan, as stated in IEA (2008b) has become a world leader in energy research. Japanese government spends the largest share, in terms of GDP, for the development of new energy technologies compare to other IEA countries. Furthermore, Japan is the third largest oil-consuming country globally after USA and China.

As illustrated in figure 4.32, Japan's energy mix in 2008 was quite well diversified, including five sources of energy. The share of oil (43%) was high, compared to other IEA countries and Japanese government has set a target of reducing the share in low level by 2030 (IEA, 2008b). It is notable that the proportion of oil in energy mix has remarkable decreased. In 1980 the share of oil in energy mix was over than 70% (IEA, 2010c). Solid fuels (23%) and natural gas (23%) have a major role in Japan's energy mix. Nuclear energy accounted for 14% while renewable resources accounted only for 3%. Despite that Japan has the second-largest amount of installed solar photovoltaics capacity globally, and it is the largest producer of solar panels, (IEA, 2008b) the proportion of renewable sources in energy supply is extremely low.

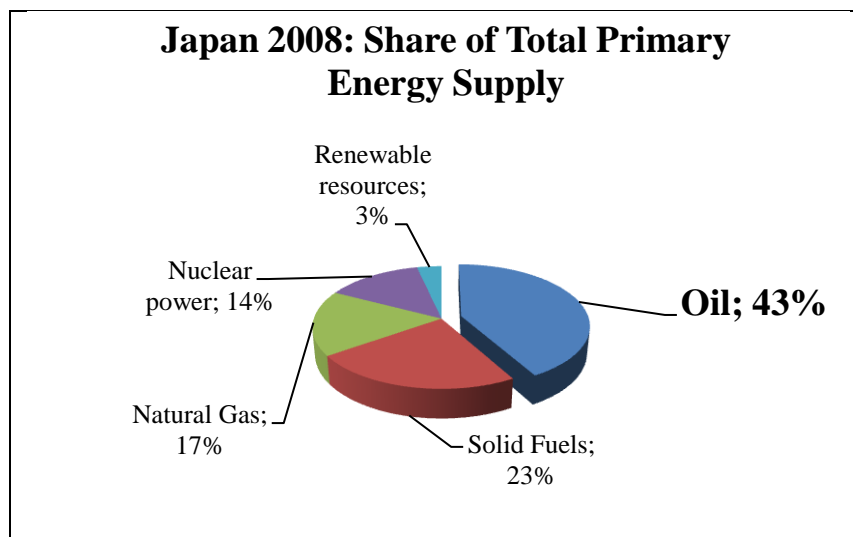


Figure 4.32: Japan: Share of Total Primary Energy Supply in 2008
Source: BP, Statistical Review of World Energy, 2010

Total Final Energy Consumption in Japan accounted for 320 Mtoe in 2008. Industry was the largest energy consuming sector in 2008 accounted for 31% of the total final consumption, followed by transportation (28%) and commercial (17%) sector.

According to IEA (2008b), the largest proportion of oil was consumed by the transportation sector.

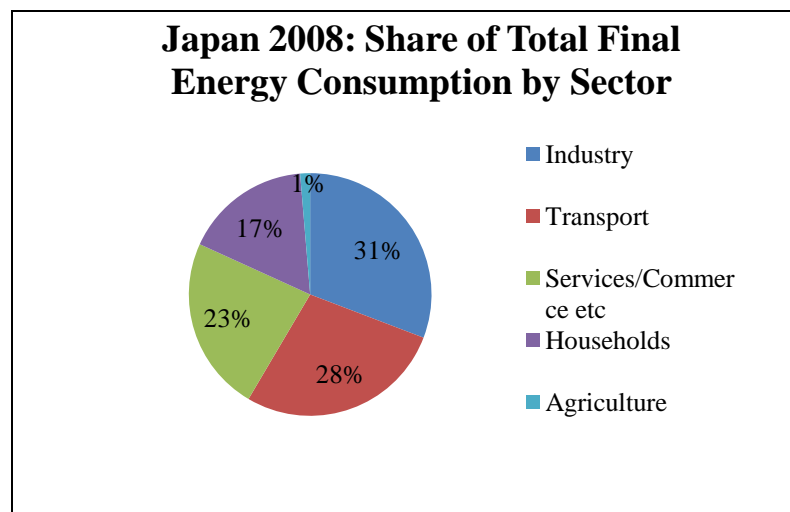


Figure 4.33: Japan: Share of Total Final Energy Consumption by Sector in 2008
Source: IEA, <http://www.iea.org/stats/index.asp>

Japan does not have significant amounts of domestic energy source production and consequently is heavily reliant upon energy imports. As reported by IEA (2008b), Japan is the largest importer of coal and natural gas globally and the second largest importer of fossil fuels among the IEA countries, after USA. Crude oil imports come mainly from Saudi Arabia and United Arab Emirates.

Japan is the second largest economy globally after the United States of America. The strong economic growth that Japan experience stem mainly from its advanced manufacturing sector. Figure 4.34 shows the historical evolution of real GDP per capita compared to oil consumption per capita. The average annual rate of growth of real GDP per capita over the period 1980-2009 is 1.85% while the associated oil consumption per capita rate is -0.61%.

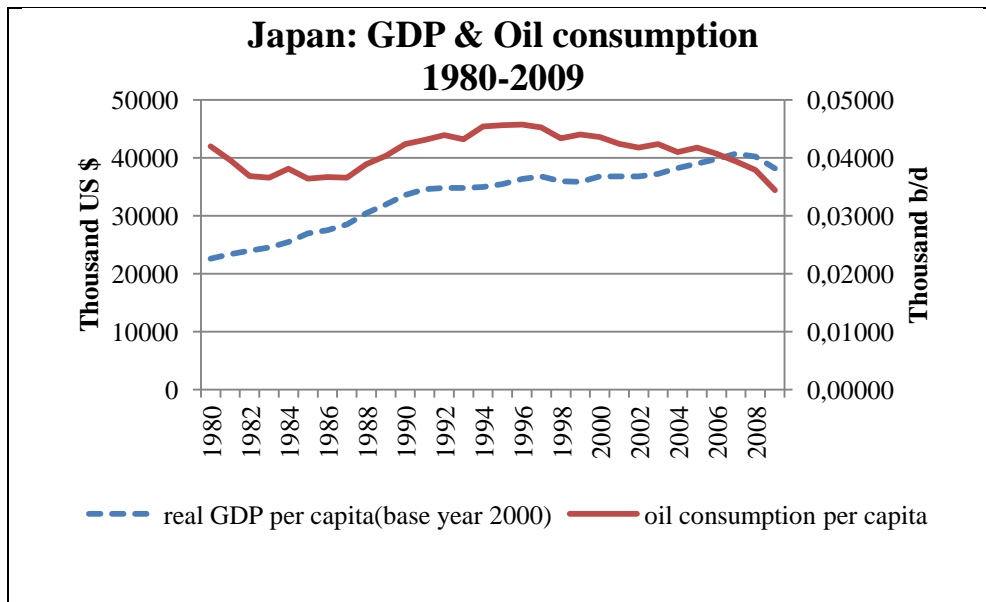


Figure 4.34: Japan: Historical relationship between oil consumption and GDP
Source: BP, Statistical Review of World Energy, 2010 – World Bank

It is clear from the figures and the facts above that all countries have experienced a great economic growth throughout the years under investigation. Oil share has a dominant position of countries' total primary energy supply in 2008 ranging from 29% to 55%, indicating the strong reliance of countries' energy mix upon oil. It is notable that only in two countries oil is not the major fuel. Specifically nuclear power has the dominating position in Sweden's energy supply while natural gas has a dominant share in Turkey's energy mix.

5. The Empirical Model

This chapter provides the reader with the empirical model and tests used in this master thesis along with the statistical findings of the thesis. In first section the regression model is illustrated. The next two sections deal with the tests of autocorrelations and the remedial measures in the existence of serial correlation. The last section presents the empirical analysis of this study.

5.1 The Regression Model

In this study a multiple regression model based on an adaptation of Nerlove's partial adjustment model is used for the estimation of price and income elasticities of crude oil demand both in the long-run and the short-run for the time period 1980-2009.

We assume that oil demand is a function of world real oil prices, real GDP per capita, oil consumption per capita lagged one year and a time trend. Thereafter, crude oil demand can be explained by the following multiple regression model:

$$\ln D_t = \alpha + \beta \ln P_t + \gamma \ln Y_t + \delta \ln D_{t-1} + \varepsilon \ln T + u_t, \quad (5.1)$$

in which , D_t is the crude oil consumption per capita in year t , P_t is the real crude oil price in year t , Y_t refers to country's real GDP per capita in year t , D_{t-1} is the crude oil consumption per capita lagged one year, T represents a time trend, u_t , is an error term, α is a constant and β ; γ ; δ ; ε are coefficients to be estimated. Crude oil consumption and crude oil prices are collected from "Statistical Review of World Energy" published by British Petroleum (BP) in 2010, while real GDP per capita is derived from the statistical database of World Bank. The statistical programme that is used for the estimation of the model is the EViews 6.0.

As can be seen variables are in per capita and real terms. Using real terms instead of nominal and taking per capita variables make the model more plausible. For that reason, all explanatory variables have been divided by the country's population while oil prices and GDP have been adjusted for inflation.

Crude oil consumption is expressed in thousand barrels per day. Crude oil prices are based on constant prices of 2009 and are expressed in US dollars. As reported in BP

(2010) in period 1980–1983 oil prices were based on Arabian Light posted at Ras Tanura and from 1984 until today are based on Brent oil. GDP is expressed in US dollars and based in 2000 constant prices. A time trend is used in this study and represents technological changes which affect the energy efficiency.

According to Gujarati (2009), if the model includes one or more lagged values of the dependent variable among its explanatory variables it is called an autoregressive model. Thereafter, we conclude that our model described by equation (5.1) is called autoregressive. The unknown parameters in the regression model are estimated by the usual Ordinary Least Square (OLS) method. Coefficient β that will be obtained from the estimation of equation (5.1) can be interpreted as the short-run price elasticity of crude oil demand while coefficient γ can be interpreted as the short-run income elasticity of demand. Long run price elasticity of crude oil demand is given by $\beta/(1-\delta)$ while the long-run income elasticity of demand for crude oil of each country can be obtained by $\gamma/(1-\delta)$.¹⁶

One of the most common problems of regression models containing lag variables is the phenomenon of autocorrelation between the residuals. That is, the error terms are correlated. In the existence of autocorrelation one of the classical linear regression model assumptions of zero covariance between any two error terms (u_t and u_s , $t \neq s$) given any two explanatory variables: X_t and X_s , is violated. According to Gujarati (2009) the disturbance term relating to any observation is influenced by the disturbance term relating to any other observation. Symbolically:

$$\text{Cov}(u_t, u_s) = E\{[u_t - E(u_t)] [u_s - E(u_s)]\} = E(u_t, u_s) \neq 0, \quad t \neq s. \quad (5.2)$$

In the presence of serial autocorrelation the OLS estimators are still linear unbiased and consistent but the assumption of efficiency is violated. In other words the coefficients do not have minimum variance. The coefficient variances are biased and as a result coefficients are not efficient anymore. OLS does not exploit the data at hand to give the most efficient estimate of the parameters in the model (Thejill and Schmith, 2005).

In this study the Breusch-Godfrey Lagrange multiplier test is used for detecting autocorrelation. If the autocorrelation exists, the coefficients will be estimated by the

¹⁶ See Appendix B.

Cochrane-Orcutt iterative procedure instead of the usual OLS. A 5% significance level has been assumed throughout the study. Finally, it is considered that the error term follows the first order autoregressive scheme – AR(1) -. That is, the regression of disturbance term on itself lagged one period Cryer (2008). According to Gujarati (2009), the AR(1) is used due to its simplicity compared to higher-order AR schemes such as AR(2), AR(3), AR(4) etc. Another reason that the AR(1) is employed is the significant amount of academic empirical studies that have been conducted using the autoregressive first-order scheme. Therefore, there is no reason to assume more than one lag.

5.2 Tests of Autocorrelation

We have assumed that there is a first-order autocorrelation between the disturbance terms ordered in time. Hence, the error term in the autoregression model in equation (5.1) can be described by the following mechanism which is known as a Markov first-order autoregression scheme:

$$u_t = \rho u_{t-1} + \varepsilon_t, \quad -1 < \rho < 1, \quad (5.3)$$

where ρ is the first-order coefficient of autocorrelation, and ε is a white noise error term or a stochastic disturbance term.

Equation (5.3) says that the value of the residual in period t is equal to the coefficient of autocorrelation at lag 1 times its value in previous period plus a stochastic error term. According to Cryer (2008), the white noise error term is a stationary process. That is, its mean, variance and covariance do not change over time. It can also be interpreted as an error term that satisfies the OLS assumptions (Gauss-Markov assumptions):

$$E(\varepsilon_t) = 0; \quad (5.4)$$

$$V(\varepsilon_t) = \sigma^2; \quad (5.5)$$

$$\text{Cov}(\varepsilon_t, \varepsilon_{t-1}) = 0. \quad (5.6)$$

There are various methods and tests of detection of serial correlation between the disturbance terms. These tests are the graphical method, the runs test, the Durbin-

Watson d test, h-test, and the Breusch-Godfrey Lagrange multiplier test. Graphical method is a qualitative method, while the rest are statistical quantitative tests. In this section we will deal only with the Durbin-Watson d and h-test and the Breusch-Godfrey Lagrange multiplier test.

5.2.1 The Durbin –Watson d test and the h-test

Durbin-Watson d statistic is the most common test for detecting serial correlation among the residuals (Gujarati, 2009). It is defined as:

$$d = \frac{\sum_{t=2}^{t=n} (\hat{u}_t - \hat{u}_{t-1})^2}{\sum_{t=1}^{t=n} \hat{u}_t^2}, \quad (5.7)$$

where \hat{u}_t is the estimated is the estimated residual for period t.

According to Gujarati (2009), since $\sum \hat{u}_t^2$ and $\sum \hat{u}_{t-1}^2$ are approximately equal if the sample is large we have:

$$d = 2(1 - \hat{\rho}) \quad (5.8)$$

Due to $-1 \leq \rho \leq 1$, equation (5.8) implies that d lies between 0 and 4. Thus, if $\hat{\rho} = +1$ then $d=0$, if $\hat{\rho} = -1$, then $d=4$ and when $\hat{\rho} = 0$ then $d=2$. According to Maddala (1988), if $d=2$ implies that there is no first-order autocorrelation if d is close to 0 indicates positive serial correlation and if d is close to 4 indicates evidence of negative serial correlation among the residuals.

There are some assumptions underlying the Durbin-Watson d test. According to Gujarati (2009), these assumptions are:

1. The explanatory variables are nonstochastic.
2. The error terms are generated by the first-order autoregressive scheme (equation 5.3). That is, it cannot be used to detect high order autoregressive schemes.
3. The error term follow the normal distribution.
4. The regression model does not include the lagged value(s) of the dependent variable as one of the explanatory variables.

Due to the fourth assumption, the Durbin-Watson d statistic is not applicable in our case since there is a lagged dependent variable among the explanatory variables (see equation 5.1). According to Gujarati (2009), the d value in a regression model containing lagged value(s) of the regressand is often around 2 which suggests that there is no first-order autocorrelation. However, this does not mean that autoregressive models do not present autocorrelation problems. For that reason Durbin suggests an alternative test called the h -test (Maddala, 1988). Durbin's h -test is defined as:

$$h = \hat{\rho} \sqrt{\frac{n}{1 - nV(\hat{\delta})}}, \quad (5.9)$$

where n is the sample size, $\hat{\delta}$ is the coefficient of the lagged D_{t-1} in equation (5.1), $V(\hat{\delta})$ is the estimated variance of the OLS estimate of δ and $\hat{\rho}$ is the estimate of the first-order serial correlation from the OLS residuals. For large sample size statistic h follows the standard normal distribution (Maddala, 1988). According to Gujarati (2009), the probability of $|h| > 1.96$ is 5%, thereafter if $|h| > 1.96$ there is evidence of first-order autocorrelation.

According to Gujarati (2009), h -test is a large sample test and its application in small samples is not strictly justified. On the other hand, the Breusch-Godfrey Lagrange Multiplier test is statistically more powerful than the h -test not only in the large samples but also in finite or small samples. As a result Breusch-Godfrey Lagrange Multiplier test is proffered to the h -test.

5.2.2 The Breusch-Godfrey Lagrange Multiplier test

With the Breusch-Godfrey Lagrange Multiplier test we test the following null hypothesis against the alternative hypothesis:

$$H_0: \rho = 0$$

$$H_1: \rho \neq 0.$$

That is, we test the null hypothesis of no serial correlation of first-order against the alternative of existence autocorrelation among the residuals. The test can be done

either by chi-square distribution or F-distribution. For simplicity, the chi-square distribution is used in this master thesis. According to Gujarati (2009) the Breusch-Godfrey Lagrange Multiplier test involves the following steps:

1. Estimate equation (5.1) by using the usual OLS method and obtain the disturbance term \hat{u} .
2. Estimate the following regression:

$$\hat{u} = \alpha_1 + a_2 \text{Ln}P_t + a_3 \text{Ln}Y_t + a_4 \text{Ln}D_{t-1} + a_5 \text{Ln}T + \hat{\rho}u_{t-1} + \varepsilon_t. \quad (5.10)$$

3. The statistic $(n - \rho) R^2$, where n is the sample and R^2 the coefficient of determination, follows the chi-square distribution with $\rho=1$ degrees of freedom. Note that in EViews the statistic $(n - \rho) R^2$ is represented by the following notation: “Observed R-squared”.
4. The null hypothesis of no serial correlation is rejected in favor of the alternative hypothesis if:

$$(n - \rho) R^2 > X_{\alpha}^2.$$

That is, if the statistic $(n - \rho) R^2$ exceeds the critical chi-square value given the significance level. For this study, given $n=30$ observations and $\rho = 1$ the chi-square critical value is 3.84 at the 5% significance level.

5.3 Remedial Measures for Autocorrelation

After the application of Breusch-Godfrey Lagrange Multiplier test and the evidence of serial correlation in the residuals we have to employ some remedial measures in order to estimate the coefficients. The remedy that should be used depends on several factors such as the size of the sample that is used and whether or not the autocorrelation coefficient ρ is known.

According to Gujarati (2009), the method of Generalized Least Squares (GLS) and the Newey- West method can be used for the estimation of coefficients in the presence of autocorrelation. GLS is nothing but OLS applied to a regression in a difference form that satisfies the classical assumptions (equations 5.4 - 5.6). On the other hand instead of using GLS methods someone could use OLS but correct the standard errors for autocorrelation by the Newey-West method (Gujarati, 2009).

Because Newey – West procedure is strictly speaking valid in large samples is not appropriate in our case, where a small sample (30 observations) is used. Thereafter the method of GLS is employed in this study.

We consider two cases in which ρ is known and ρ is not known but need to be estimated.

ρ is known

Consider the multiple regression model of equation (5.1)¹⁷:

$$D_t = \alpha + \beta P_t + \gamma Y_t + \delta D_{t-1} + u_t. \quad (5.1)'$$

We assume that the disturbance term follows the AR(1) scheme as in equation (5.3). If equation (5.1)' holds true at time t , it also holds true at time $(t-1)$. Hence:

$$D_{t-1} = \alpha + \beta P_{t-1} + \gamma Y_{t-1} + \delta D_{t-2} + u_{t-1}. \quad (5.11)$$

We multiply equation (5.11) by ρ on both sides and we get:

$$\rho D_{t-1} = \rho\alpha + \rho\beta P_{t-1} + \rho\gamma Y_{t-1} + \rho\delta D_{t-2} + \rho u_{t-1}. \quad (5.12)$$

Subtracting equation (5.12) from (5.1)' we obtain:

$$\begin{aligned} (D_t - \rho D_{t-1}) &= \alpha(1 - \rho) + \beta(P_t - \rho P_{t-1}) + \gamma(Y_t - \rho Y_{t-1}) \\ &\quad + \delta(D_{t-1} - \rho D_{t-2}) + v_t, \end{aligned} \quad (5.13)$$

where $v_t = (u_t - \rho u_{t-1})$.

Since v_t satisfies the Gauss – Markov assumption we can apply the OLS in equation (5.13) and obtain BLUE estimators.

ρ is not known

The method of generalized difference given in equation (5.13) is difficult to implement because ρ is rarely known in practice (Gujarati, 2009). So, some methods needs to be found for estimating ρ . The methods that can be used are: the first-difference method, ρ based on Durbin-Watson d statistic, ρ estimated from the

¹⁷ For simplicity we do not expressed equation (5.1) in a natural logarithmic form and we have omitted the time trend variable.

residuals and iterative methods of estimating ρ (Gujarati, 2009). In this study an iterative method of estimating ρ and specifically the Cochrane-Orcutt iterative procedure is employed.

5.3.1 The Cochrane-Orcutt iterative procedure

According to Gujarati (2009), the Cochrane-Orcutt iterative procedure has become quite popular. Cochrane-Orcutt iterative procedure estimates the correlation coefficient iteratively. In other words, the estimation of the first-order coefficient of autocorrelation is done by successive approximations of it, starting with some initial value of the autocorrelation coefficient.

According to Gujarati (2009), Cochrane-Orcutt includes the following steps for the estimation of ρ :

1. We estimate equation (5.1)' by the usual OLS method and we obtain the residuals \hat{u}_t .
2. Using \hat{u}_t we run the following regression:

$$\hat{u}_t = \hat{\rho}\hat{u}_{t-1} + v_t. \quad (5.14)$$

3. Use $\hat{\rho}_t$ obtained in equation (5.14) we estimate the generalized difference equation (5.13).
4. Since it is known if the $\hat{\rho}_t$ obtained from equation (5.14) is the best estimate of ρ , we substitute the values of $\hat{\alpha}^*$, $\hat{\beta}^*$, $\hat{\gamma}^*$, and $\hat{\delta}^*$ obtained in step 3 in the original regression equation (5.1)' and we obtain the new residuals:

$$\hat{u}_t^* = D_t - \hat{\alpha}^* - \hat{\beta}^*P_t - \hat{\gamma}^*Y_t - \hat{\delta}^*D_{t-1}, \quad (5.15)$$

which can easily be computed since D_t , P_t , Y_t , $\hat{\alpha}^*$, $\hat{\beta}^*$, $\hat{\gamma}^*$, and $\hat{\delta}^*$ are all known.

5. Now we estimate the following regression:

$$\hat{u}_t^* = \hat{\rho}^*\hat{u}_{t-1}^* + w_t, \quad (5.16)$$

which is similar to equation (5.14) and thus provides the second-order estimate ρ .

Since it is impossible to know if this second-round estimate of ρ is the best estimate of the true ρ , we go into the third- round estimate and so on.

According to Gujarati (2009), one advantage of the Cochrane-Orcutt iterative method is that it can be used to estimate not only an AR(1) scheme but also higher –order autoregressive schemes such as AR(2): $\hat{u}_t = \hat{\rho}_1 \hat{u}_{t-1} + \hat{\rho}_2 \hat{u}_{t-2} + v_t$. Moreover, the strength of the Cochrane-Orcutt method is that introduces one extra parameter only, thus minimizing the risk of overfitting (Thejill and Schmith, 2005)

In the generalized equation (5.13) we lose one observation due to the fact that the first observation has no antecedent. This loss of one observation can be avoided using the Prais-Winsten transformation (Gujarati, 2009). That is, that the first observation on D, P, and Y is transformed as follows: $D_1\sqrt{(1-\rho^2)}$, $P_1\sqrt{(1-\rho^2)}$ and $Y_1\sqrt{(1-\rho^2)}$. In small samples it is important to keep the first observation *à la* Prais-Winsten otherwise we drop that observation and the results are substantially different. In this study we have decided to estimate the coefficients without transforming the first observation *à la* Prais-Winsten since EViews does not offer the Prais-Winsten transformation.

Maximum Likelihood estimation is another alternative that can be used for the estimation of the regression. It is offering asymptotic consistent and efficient estimated for any structure of error terms and for a wide range of models, including nonlinear regression models (Thejill and Schmith, 2005). However, Maximum Likelihood has the drawback of computational costs due to the necessary iterative procedure and the occasional lack of robustness in comparison with simpler estimators (Thejill and Schmith, 2005).

5.4 Empirical Findings and Analysis

Before the analysis of the econometric results, a general pattern for the price and income elasticities is illustrated based on empirical research. Previous empirical work and several academic studies have shown that price and income elasticities are significantly higher in the long-run than in the short-run. Both in the short-run and the long-run, the price elasticity of demand for crude oil is extremely low and specifically highly inelastic. Income elasticities are also found to be inelastic in the short-run but in the long-run are close to unity and in some cases significantly elastic.

According to economic theory, the price of good is conversely related to its quantity demanded. So, we conclude that coefficient β should be a negative number. Regarding coefficient γ we expect that it will have positive sign as the increase of a country's real output (GDP) should raise the demand for crude oil.

EViews 6.0 is used for the evaluation of the log-linear model and the estimation of price and income elasticities. The mainly econometric results from the country's regression model in equation (3) are presented in table 5.1. Specifically, table shows the estimated coefficients for the: constant parameter: α , oil price: β , real GDP per capita: γ , lagged oil consumption per capita: δ , time trend: ε

The p-values of t-statistics are shown in the parenthesis. It is clear that all the estimated coefficients are statistically significant at the 5% significance level except in case of Turkey which coefficient γ is significant at 10% level. Moreover, the estimated coefficient for the time trend T is significant at 10% level in case of Portugal while the corresponding coefficient in case of Turkey is not statistically different from zero anyway. Note that given 30 observations and 5% significance level the critical t-value is 2.042. Table 5.1 indicates that oil consumption per capita changes with respect to time in addition to oil price, real GDP per capita and the lagged oil consumption per capita. It has been stated in a previous paragraph that the variable of time trend expresses technological changes which affect the energy efficiency. It is clear from the table that all estimated time trend coefficients are negative implying that if "technology improved" by 1% the oil consumption per capita will be decreased by the estimated coefficient value.

Country	Coefficient/Variable							
	α (const.)	B (P)	γ (Y)	δ (D _{t-1})	ε (T)	R ²	F-statistic	Breusch-Godfrey
Sweden	-4.1485 (0.0039)**	-0.0500 (0.0231)**	0.3801 (0.0117)**	0.5741 (0.0002)**	-0.2788 (0.0006)**	0.95	141.248	0.0023 (0.9616)***
Denmark	-6.2572 (0.0333)**	-0.0360 (0.0483)**	0.6335 (0.0392)**	0.7440 (0.0000)**	-0.2864 (0.0323)**	0.94	110.442	3.0633 (0.0801)***
Spain	-5.8096 (0.0028)**	-0.0561 (0.0001)**	0.6622 (0.0014)**	0.7967 (0.0000)**	-0.2930 (0.0014)**	0.97	304.093	0.0352 (0.8511)***
Portugal*	-6.1939 (0.0016)**	-0.0594 (0.0007)**	0.6509 (0.0012)**	0.6643 (0.0000)**	-0.2452 (0.0748)**	0.95	95.434	3.9281 (0.0475)***
Turkey	-5.0584 (0.0026)**	-0.1045 (0.0008)**	0.4472 (0.0561)**	0.5294 (0.0031)**	-0.1444 (0.3177)**	0.90	62.353	2.1922 (0.1387)***
Finland	-4.2322 (0.0009)**	-0.0430 (0.0144)**	0.3558 (0.0041)**	0.5112 (0.0014)**	-0.2171 (0.0025)**	0.82	30.054	3.3334 (0.0679)***
Italy*	-6.0830 (0.0000)**	-0.0496 (0.0000)**	0.5999 (0.0000)**	0.6501 (0.0000)**	-0.2496 (0.0000)**	0.97	155.397	5.4536 (0.0195)***
Germany	-7.0456 (0.0157)**	-0.0686 (0.0000)**	0.5982 (0.0486)**	0.3115 (0.0199)**	-0.3116 (0.0204)**	0.85	36.567	0.5888 (0.4429)***
USA	-6.6668 (0.0001)**	-0.0392 (0.0049)**	0.5872 (0.0002)**	0.4130 (0.0000)**	-0.2646 (0.0002)**	0.90	38.000	3.3624 (0.0667)***
Japan	-5.6547 (0.0007)**	-0.0364 (0.0073)**	0.5258 (0.0016)**	0.6928 (0.0000)**	-0.2142 (0.0023)**	0.89	53.867	0.3284 (0.5665)***

Table 5.1: Summary of Regression Results

*=estimation by the Cochrane-Orcutt iterative method, **=p-value of chi-square, ***=p-value of t-statistic.

As can be seen the coefficient of determination R² range from 0.82 to 0.97 indicating that the model fits the data very well. In other words, the variation in the dependent variable D is explained in a large extent by the variation in independent variables (P, Y, D_{t-1}, and T). All F-statistic values are statistically significant at 5% significance

level implying that at least one coefficient is different from zero. Note that given 30 observations, 4 degrees of freedom for numerator and 25 degrees of freedom for denominator the critical F-value is 2.76. Finally, table shows the value of observed R^2 which have been obtained from the Breusch-Godfrey Serial Correlation Lagrange Multiplier Test. Given 30 observations and 1 (one year lag) degree of freedom the chi-square critical value is 3.84. Thereafter, it is clear than only in cases of Italy and Turkey we reject the null hypothesis of no serial correlation.

Table 5.2 illustrates the estimated price and income elasticities both in the short-run and the long-run for each country over the period 1980-2009 (the calculations for Sweden and Denmark are based on the period 1976 and 1977 respectively).

Country	Short run Price elasticity: β	Long run Price elasticity: $\frac{\beta}{(1 - \delta)}$	Short run Income elasticity: γ	Long run Income elasticity: $\frac{\gamma}{(1 - \delta)}$
Sweden	-0.050 (-2.398)*	-0.117	0.380 (2.692)*	0.892
Denmark	-0.036 (2.064)*	-0.141	0.633 (2.162)*	2.473
Spain	-0.056 (-4.636)*	-0.275	0.662 (3.582)*	3.245
Portugal	-0.059 (-3.905)*	-0.176	0.650 (3.683)*	1.935
Turkey	-0.104 (-3.793)*	-0.221	0.447 (2.003)*	0.949
Finland	-0.043 (-2.629)*	-0.088	0.355 (3.162)*	0.726
Italy	-0.049 (-11.363)*	-0.140	0.599 (5.063)*	1.711
Germany	-0.068 (-4.964)*	-0.099	0.598 (2.073)*	0.868
USA	-0.039 (-3.264)*	-0.066	0.587 (4.877)*	1.000
Japan	-0.036 (-2.923)*	-0.117	0.525 (3.535)*	1.705

Table 5.2: Short and Long run Price and Income Elasticities

*=t-statistic.

As can be seen all elasticities have theoretically correct signs and they are consistent with the majority of previous empirical research following the general pattern described above. That is:

- Short-run elasticities are lower than the long-run values.
- Price elasticities are highly inelastic both in the short-run and the long-run.
- Long-run income elasticities are close to unity or elastic.

For instance the estimated equation for the Sweden is:

$$\ln D_t = -4.148 - 0.050 \ln P_t + 0.380 \ln Y_t + 0.574 \ln D_{t-1} - 0.278 \ln T$$

The results in Sweden's case indicate that the short-run price elasticity is -0.050 meaning that if oil price increases by 1% crude oil demand will be decreased by 0.050%. As expected, price elasticity in the long-run is more elastic than in the short-run. Specifically, is estimated to -0.117 implying that a 1% increase in crude oil price leads to a 0.117% decrease in oil demand. Income elasticities have been estimated to 0.380 and 0.892 in the short-run and the long-run respectively. In contrast to oil price, real GDP has a positive relation to oil demand. For instance, if real output per capita increases by 1% oil demand per capita will be increased by 0.380% (short-run) or 0.892% (long-run). A similar interpretation can be given for the analysis of the estimated equations for the other countries.

The results of this study are quite similar with the estimates for the price and income elasticities reported by other researchers such as Cooper (2003), Altinay (2007), and Ghouri (2001).

Cooper's (2003) results are quite consistent with the results of this study with some variations among the values of the results. In Cooper's (2003) paper, short-run price elasticity in Sweden's and Denmark's case for example has been estimated to -0.043 and -0.026 respectively, while long-run price elasticity accounts for -0.289 and -0.191. Although, Cooper (2003) used the same methodology (an adaption of Nerlove's partial adjustment model) as the method employed in this thesis, he used a different time period (1971-2000) and hence fewer observations. That could explain the differences in the estimated price elasticities.

Altinay (2007) found that the short-run and the long-run price elasticity in Turkey accounts for -0.10 and -0.18 respectively while income elasticity in the short-run and in the long-run is 0.64 and 0.61. This goes in line with the results of this study where price elasticity in Turkey has been found to be -0.104 (short-term) and -0.221 (long-term) while income elasticities are estimated to be 0.447 (short-term) and 0.949 (long-term). The differences in the estimated results could be due to the fact that Altinay (2007) used a different method (autoregressive distributed lag bounds testing approach to cointegration) than the method employed in this thesis.

Ghouri (2001) found that the short-run price elasticity in USA is -0.029 while long-run price elasticity is 0.045. He estimated the long-run income elasticity to be 0.98. These values are very close to the estimates of this thesis for USA's case. The differences could be explained by the different econometric method that is employed and the different time period that is used.

The comparison of real GDP per capita growth along with the oil consumption per capita growth provides a plausible measure of any improved energy efficiency. For that reason a table has been constructed illustrating the average annual rate of real GDP per capita growth and the average annual rate of oil consumption per capita growth over the period 1980-2009.

Sweden and Denmark seem to have decreased their crude oil consumption per capita. On the other hand, Spain, Portugal and Turkey have increased their oil consumption per capita over the same period. The rest of the countries seem to have constant oil consumption throughout the years. Specifically, Finland, Germany, Italy, USA and Japan have slightly decreased their crude oil consumption since 1980. More precisely, the average annual rate of growth of oil consumption per capita in Sweden and Denmark is -1.89% and -1.55% respectively while the associated growth rate in Spain, Portugal and Turkey is 0.66%, 1.50% and 1.04% respectively. The average annual change of oil consumption per capita in Finland, Germany, Italy, USA and Japan ranges from -0.61% to 0.95%. The growth rate of real GDP per capita indicates that all economies experienced strong economic growth over the years under investigation.

Table 5.3 indicates that if oil consumption per capita grows at a smaller rate than real GDP per capita, then the rate of oil consumption in the production of real output has decreased over the years. In case of Sweden, Denmark, Finland, Italy, Germany, USA and Japan the negative oil consumption growth rate could show that their real per capita output has been fuelled by a less-energy intensive service and industrial sector.

Country	Real GDP per capita growth (%)	Oil consumption per capita growth (%)
Sweden	1.64	-1.89
Denmark	1.55	-1.55
Spain	1.99	0.66
Portugal	2.05	1.50
Turkey	2.45	1.04
Finland	1.95	-0.95
Italy	1.21	-0.91
Germany	1.56	-0.87
USA	1.73	-0.67
Japan	1.85	-0.61

Table 5.3: Annual real GDP and oil consumption per capita growth averages
Source: BP-Statistical Review of World Energy, 2010 - World Bank

6. Conclusion and Discussion

This study attempts to estimate and analyze the price and income elasticities of crude oil demand both in the short-run and the long-run for ten IEA member countries using annual data that cover the period 1980-2009. The method employed in this paper is a multiple regression model derived from an adaption of Nerlove's partial adjustment model. Sweden, Denmark, Finland, Italy, Germany, USA, and Japan have decreased their oil consumption over the time period under investigation, both in average and absolute terms. On the other hand, at the same time period, Spain Portugal and Turkey have increased their oil consumption.

All estimated elasticity coefficients are significant at the 5% significance level except in case of Turkey where short-run income elasticity coefficient is slightly insignificant at 5% significance level but significant at 1% level. The estimated coefficients have the correct expected signs. Price and income elasticities go in line with economic theory having negative and positive signs respectively. The time trend as has been stated was introduced to capture the technological changes-progress. Econometric results showed that coefficients of the time trend are statistically significant at 5% significance level (except in case of Turkey and Portugal where is significant at 1% level) and have negative sign indicating that countries have made significant improvements over the time for the reducing of oil intensity. The results have shown that the short-run elasticities are lower than the corresponding long-run elasticities indicating that countries are more responsive in the long-run than in the short-run. Price elasticities are highly inelastic both in the short-run and the long-run and long-run income elasticities are close to unity and in some countries are elastic. Precisely, short-run price elasticities range from -0.104 to -0.036 while long-run price elasticities are more elastic ranging from -0.275 to -0.066. Short-run income elasticities range from 0.355 to 0.662 and the corresponding long-run elasticities range from 0.726 to 2.473.

These values are very close to the estimates for the price and income elasticities conducted by Cooper (2003) who used the same econometric technique as the method employed in this thesis. However, there are some variations among the estimated coefficients due to the fact that Cooper (2003) used a different time-span: 1979-200.

Estimates results are also comparable with the results derived by other scientists such as Altinay (2007) or Ghouri (2001). In such cases, the differences in the values of estimated elasticities could be explained by the application of different econometric techniques and the use of different time periods that researchers used.

Crude oil demand is highly price-inelastic indicating that consumers (or countries) are insensitive to price changes implying that countries have difficulty in finding alternative energy sources. That makes countries to be vulnerable to oil price shocks. Increases of oil prices have a negative effect in countries' trade balance. The fact that short-run price elasticities are lower than the long-run elasticities could be explained by the necessary time-lag that countries need to respond to price changes (the same holds for income elasticities).

Income elasticities indicate that crude oil is a normal good, since oil demand increases in line with an increase in real income. Short-run income elasticities are lower than unity, indicating that crude oil demand grows at a smaller rate than income and oil intensity has been reducing over time. For example, If Sweden's output increases by 1% per year, the demand for crude oil will increase by 0.89% annually, and as a result oil intensity will decline *ceteris paribus* by 0.11% annually. The latter does not hold for all countries in the long-run. Specifically, in case of Denmark, Spain, Portugal, Italy, and Japan (their long-run income elasticity is greater than one) crude oil demand grows at a greater rate than income and one can assume that these countries have limited ability to find a substitute for crude oil.

Someone could analyze various topics related to this study. It would be interesting to estimate and analyze along with the price and income elasticities of crude oil demand, the corresponding elasticities of natural gas demand. Another topic that someone could study is how oil prices could affect a country's GDP or the impact of oil prices on serious macroeconomic variables such as unemployment, inflation, trade balance etc. Another appealing topic for further research could be the effect of Peak Oil on a country's economy based that in such case oil prices will dramatically increase. Finally, one could forecast crude oil demand globally or in a given country by a certain year through price and income elasticities based on time series data.

Appendix A

Price and Income Elasticity

The price elasticity of demand E_D^P is a measure of how much the quantity demanded of a good responds to a change in the price of that good, computed as the percentage change in quantity demanded divided by the percentage change in price (Mankiw, 2006). Similarly, the income elasticity of demand E_D^Y is a measure indicating the responsiveness or sensitivity of the quantity demanded of a good to a change in income, computed as the percentage change in quantity demanded divided by the percentage change in income (Mankiw, 2006).

Hence, we can denote the two elasticities as:

$$\text{Price elasticity of demand} = \frac{\text{percentage change in quantity demanded}}{\text{percentage change in price}}$$

$$\text{Income elasticity of demand} = \frac{\text{percentage change in quantity demanded}}{\text{percentage change in income}}$$

And mathematically as:

$$E_D^P = \frac{\Delta Q\%}{\Delta P\%} = \frac{\Delta Q}{\Delta P} * \frac{P}{Q}, \quad (\text{A.1})$$

$$E_D^Y = \frac{\Delta Q\%}{\Delta Y\%} = \frac{\Delta Q}{\Delta Y} * \frac{Y}{Q}, \quad (\text{A.2})$$

where Q is the quantity demanded, P is the good's price and Y refers to country's output.

We distinguish between three different types of elasticity of demand for a good: inelastic, elastic and unit elastic.

According to Mankiw (2006) the demand for a good is said to be elastic if the quantity demanded responds substantially to changes in price (income). That is:

$$|E_D^P(E_D^Y)| > 1 \leftrightarrow |\Delta Q\%| > |\Delta P\%(\Delta Y\%)|.$$

On the other hand the demand for a good is said to be inelastic if the quantity demanded responds only slightly to changes in price (income). That is:

$$|E_D^P(E_D^Y)| < 1 \leftrightarrow |\Delta Q\%| < |\Delta P\%(\Delta Y\%)|.$$

Finally the demand for a good is unit elastic if the quantity demanded responds to the same degree to changes in price (income). That is:

$$|E_D^P(E_D^Y)| = 1 \leftrightarrow |\Delta Q\%| = |\Delta P\%(\Delta Y\%)|.$$

In this thesis the concept of elasticity refers to changes of a country's crude oil demand due to a change in world oil price (price elasticity) or a change in a country's real per capita income (income elasticity). If the degree of sensitivity of crude oil demand to price (or income) changes is low, we refer to price and income inelasticity. On the other hand, if the quantity of oil demanded responds significantly to price and income changes we say that demand for crude oil is elastic.

Appendix B

The Theoretical Underpinning of the Model¹⁸

Assume a hypothetical economy that wants to reduce its crude oil consumption. Due to technical rigidities the reduction of oil consumption cannot be succeeded within a single period and only a partial adjustment can be made each period. This situation can be captured by the following adaption of Nerlove's partial adjustment model.

We denote the long-run crude oil demand function as:

$$D_t^L = \alpha P_t^\beta Y_t^\gamma u_t, \quad (\text{B. 1})$$

and the gradual adjustment process is given by:

$$\frac{D_t^L}{D_t^S} = \left[\frac{D_t^L}{D_{t-1}^S} \right]^\delta, \quad (\text{B. 2})$$

where D_t^L is the long run crude oil demand in year t , D_t^S is the short-run crude oil demand in year t , β is the long run price elasticity of crude oil demand, γ is the long-run income elasticity of crude oil demand and $0 < \delta \leq 1$ is the coefficient of adjustment.

Solving in equation (B.2) for D_t^L we obtain:

$$D_t^L = \left[\frac{D_t^S}{(D_{t-1}^S)^\delta} \right]^{\frac{1}{1-\delta}}. \quad (\text{B. 3})$$

Substituting equation (B.3) in equation (B.1) we get:

$$\left[\frac{D_t^S}{(D_{t-1}^S)^\delta} \right]^{\frac{1}{1-\delta}} = \alpha P_t^\beta Y_t^\gamma u_t. \quad (\text{B. 4})$$

Solving in equation (B.4) for D_t^S we get:

¹⁸ This section leans heavily on Cooper's (2003) paper.

$$D_t^s = \alpha^{(1-\delta)} P_t^{\beta(1-\delta)} Y_t^{\gamma(1-\delta)} (D_{t-1}^s)^\delta u_t^{(1-\delta)}. \quad (\text{B.5})$$

Taking of both sides of equation (B.6) we obtain:

$$\begin{aligned} \text{Ln} D_t^s &= (1 - \delta) \text{Ln } \alpha + \beta(1 - \delta) \text{Ln } P_t + \gamma(1 - \delta) \text{Ln } Y_t + \delta \text{Ln } D_{t-1}^s \\ &\quad + (1 - \delta) \text{Ln } u_t. \end{aligned} \quad (\text{B.6})$$

Equation (B.6) is the same as equation (5.1) and its theoretical underpinning. The short-run price elasticity of crude oil demand is given by $\beta(1-\delta)$ which is equal to β in equation (5.1). Similarly the short-run income elasticity is given by $\gamma(1-\delta)$ which corresponds to γ in equation (5.1). Long-run price and income elasticity are given by β and γ respectively which are equivalent to $\beta/(1-\delta)$ and $\gamma/(1-\delta)$ in equation (5.1).

Appendix C

Regression Results

$C = \alpha$ = constant coefficient

(X1) = oil consumption variable

(X2) = β = real oil price coefficient

(X3) = γ = real GDP per capita coefficient

(X1(-1)) = δ = oil consumption lagged one year coefficient

(@TREND) = ε = time trend coefficient

1. Sweden

Dependent Variable: LOG(X1)

Method: Least Squares

Date: 06/12/11 Time: 13:27

Sample: 1976 2009

Included observations: 34

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-4.148556	1.323583	-3.134339	0.0039
LOG(X2)	-0.050020	0.020857	-2.398265	0.0231
LOG(X3)	0.380150	0.141214	2.692018	0.0117
LOG(X1(-1))	0.574166	0.133982	4.285404	0.0002
LOG(@TREND)	-0.278801	0.072272	-3.857677	0.0006
R-squared	0.951178	Mean dependent var	-3.113935	
Adjusted R-squared	0.944444	S.D. dependent var	0.183943	
S.E. of regression	0.043356	Akaike info criterion	-3.303688	
Sum squared resid	0.054513	Schwarz criterion	-3.079223	
Log likelihood	61.16269	Hannan-Quinn criter.	-3.227139	
F-statistic	141.2481	Durbin-Watson stat	1.911038	
Prob(F-statistic)	0.000000			

Breusch-Godfrey Serial Correlation LM Test:

F-statistic	0.001904	Prob. F(1,28)	0.9655
Obs*R-squared	0.002312	Prob. Chi-Square(1)	0.9616

2. Denmark

Dependent Variable: LOG(X1)
Method: Least Squares
Date: 06/13/11 Time: 13:51
Sample: 1977 2009
Included observations: 33

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-6.257257	2.794363	-2.239243	0.0333
LOG(X2)	-0.036088	0.017480	-2.064570	0.0483
LOG(X3)	0.633513	0.292907	2.162846	0.0392
LOG(X1(-1))	0.744059	0.101437	7.335181	0.0000
LOG(@TREND)	-0.286472	0.127175	-2.252573	0.0323
R-squared	0.940396	Mean dependent var	-3.201403	
Adjusted R-squared	0.931881	S.D. dependent var	0.170526	
S.E. of regression	0.044506	Akaike info criterion	-3.247639	
Sum squared resid	0.055463	Schwarz criterion	-3.020896	
Log likelihood	58.58605	Hannan-Quinn criter.	-3.171347	
F-statistic	110.4424	Durbin-Watson stat	1.427056	
Prob(F-statistic)	0.000000			

Breusch-Godfrey Serial Correlation LM Test:

F-statistic	2.762842	Prob. F(1,27)	0.1080
Obs*R-squared	3.063342	Prob. Chi-Square(1)	0.0801

3. Spain

Dependent Variable: LOG(X1)
Method: Least Squares
Date: 06/10/11 Time: 15:23
Sample: 1980 2009
Included observations: 30

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-5.809682	1.749302	-3.321144	0.0028
LOG(X2)	-0.056179	0.012116	-4.636925	0.0001
LOG(X3)	0.662299	0.184883	3.582261	0.0014
LOG(X1(-1))	0.796759	0.091303	8.726498	0.0000
LOG(@TREND)	-0.293015	0.081330	-3.602804	0.0014
R-squared	0.979861	Mean dependent var	-3.506846	
Adjusted R-squared	0.976639	S.D. dependent var	0.158564	
S.E. of regression	0.024235	Akaike info criterion	-4.450986	
Sum squared resid	0.014684	Schwarz criterion	-4.217453	
Log likelihood	71.76479	Hannan-Quinn criter.	-4.376277	
F-statistic	304.0934	Durbin-Watson stat	1.870879	
Prob(F-statistic)	0.000000			

Breusch-Godfrey Serial Correlation LM Test:

F-statistic	0.028236	Prob. F(1,24)	0.8680
Obs*R-squared	0.035254	Prob. Chi-Square(1)	0.8511

4a. Portugal

Dependent Variable: LOG(X1)

Method: Least Squares

Date: 06/10/11 Time: 15:37

Sample: 1980 2009

Included observations: 30

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-8.136316	2.179633	-3.732884	0.0010
LOG(X2)	-0.066693	0.020801	-3.206280	0.0037
LOG(X3)	0.815285	0.232485	3.506827	0.0017
LOG(X1(-1))	0.520612	0.133382	3.903172	0.0006
LOG(@TREND)	-0.266687	0.110417	-2.415273	0.0234
R-squared	0.946366	Mean dependent var	-3.715212	
Adjusted R-squared	0.937785	S.D. dependent var	0.209343	
S.E. of regression	0.052217	Akaike info criterion	-2.915824	
Sum squared resid	0.068164	Schwarz criterion	-2.682291	
Log likelihood	48.73736	Hannan-Quinn criter.	-2.841115	
F-statistic	110.2805	Durbin-Watson stat	2.447793	
Prob(F-statistic)	0.000000			

4b. Portugal

Dependent Variable: LOG(X1)

Method: Least Squares

Date: 06/10/11 Time: 21:01

Sample: 1980 2009

Included observations: 30

Convergence achieved after 6 iterations

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-6.193958	1.743070	-3.553476	0.0016
LOG(X2)	-0.059483	0.015229	-3.905863	0.0007
LOG(X3)	0.650963	0.176735	3.683263	0.0012
LOG(X1(-1))	0.664372	0.114243	5.815442	0.0000
LOG(@TREND)	-0.245214	0.077360	-3.169785	0.0041
AR(1)	-0.387693	0.208145	-1.862606	0.0748
R-squared	0.952113	Mean dependent var	-3.715212	
Adjusted R-squared	0.942136	S.D. dependent var	0.209343	
S.E. of regression	0.050357	Akaike info criterion	-2.962487	
Sum squared resid	0.060861	Schwarz criterion	-2.682247	
Log likelihood	50.43730	Hannan-Quinn criter.	-2.872836	
F-statistic	95.43498	Durbin-Watson stat	2.263028	
Prob(F-statistic)	0.000000			
Inverted AR Roots	-.39			

Breusch-Godfrey Serial Correlation LM Test:

F-statistic	3.615965	Prob. F(1,24)	0.0693
Obs*R-squared	3.928125	Prob. Chi-Square(1)	0.0475

5. Turkey

Dependent Variable: LOG(X1)

Method: Least Squares

Date: 06/10/11 Time: 17:45

Sample: 1980 2009

Included observations: 30

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-5.058444	1.515713	-3.337336	0.0026
LOG(X2)	-0.104592	0.027575	-3.793025	0.0008
LOG(X3)	0.447264	0.223288	2.003081	0.0561
LOG(X1(-1))	0.529433	0.161654	3.275111	0.0031
LOG(@TREND)	-0.144487	0.141723	-1.019499	0.3177
R-squared	0.908897	Mean dependent var	-4.772675	
Adjusted R-squared	0.894321	S.D. dependent var	0.144613	
S.E. of regression	0.047011	Akaike info criterion	-3.125851	
Sum squared resid	0.055251	Schwarz criterion	-2.892319	
Log likelihood	51.88777	Hannan-Quinn criter.	-3.051142	
F-statistic	62.35379	Durbin-Watson stat	2.280761	
Prob(F-statistic)	0.000000			

Breusch-Godfrey Serial Correlation LM Test:

F-statistic	1.892021	Prob. F(1,24)	0.1817
Obs*R-squared	2.192206	Prob. Chi-Square(1)	0.1387

6. Finland

Dependent Variable: LOG(X1)

Method: Least Squares

Date: 06/10/11 Time: 15:33

Sample: 1980 2009

Included observations: 30

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-4.232222	1.128965	-3.748763	0.0009
LOG(X2)	-0.043030	0.016365	-2.629308	0.0144
LOG(X3)	0.355821	0.112523	3.162209	0.0041
LOG(X1(-1))	0.511296	0.142237	3.594673	0.0014
LOG(@TREND)	-0.217183	0.064501	-3.367110	0.0025
R-squared	0.827843	Mean dependent var	-3.134144	
Adjusted R-squared	0.800298	S.D. dependent var	0.061959	
S.E. of regression	0.027688	Akaike info criterion	-4.184596	
Sum squared resid	0.019166	Schwarz criterion	-3.951063	
Log likelihood	67.76894	Hannan-Quinn criter.	-4.109887	
F-statistic	30.05401	Durbin-Watson stat	2.346980	
Prob(F-statistic)	0.000000			

Breusch-Godfrey Serial Correlation LM Test:

F-statistic	3.000111	Prob. F(1,24)	0.0961
Obs*R-squared	3.333443	Prob. Chi-Square(1)	0.0679

7a. Italy

Dependent Variable: LOG(X1)

Method: Least Squares

Date: 06/10/11 Time: 16:14

Sample: 1980 2009

Included observations: 30

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-7.124173	1.714298	-4.155739	0.0003
LOG(X2)	-0.052224	0.006793	-7.688306	0.0000
LOG(X3)	0.694209	0.170176	4.079356	0.0004
LOG(X1(-1))	0.579750	0.092770	6.249305	0.0000
LOG(@TREND)	-0.284189	0.063335	-4.487091	0.0001
R-squared	0.959852	Mean dependent var	-3.429282	
Adjusted R-squared	0.953429	S.D. dependent var	0.068871	
S.E. of regression	0.014863	Akaike info criterion	-5.428915	
Sum squared resid	0.005522	Schwarz criterion	-5.195382	
Log likelihood	86.43372	Hannan-Quinn criter.	-5.354205	
F-statistic	149.4255	Durbin-Watson stat	2.725635	
Prob(F-statistic)	0.000000			

7b. Italy

Dependent Variable: LOG(X1)

Method: Least Squares

Date: 06/10/11 Time: 16:15

Sample: 1980 2009

Included observations: 30

Convergence achieved after 8 iterations

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-6.083001	1.187289	-5.123437	0.0000
LOG(X2)	-0.049671	0.004371	-11.36343	0.0000
LOG(X3)	0.599970	0.118478	5.063989	0.0000
LOG(X1(-1))	0.650135	0.062101	10.46905	0.0000
LOG(@TREND)	-0.249651	0.043992	-5.674960	0.0000
AR(1)	-0.457996	0.157731	-2.903643	0.0078
R-squared	0.970037	Mean dependent var	-3.429282	
Adjusted R-squared	0.963795	S.D. dependent var	0.068871	
S.E. of regression	0.013105	Akaike info criterion	-5.654846	
Sum squared resid	0.004122	Schwarz criterion	-5.374607	
Log likelihood	90.82269	Hannan-Quinn criter.	-5.565195	
F-statistic	155.3973	Durbin-Watson stat	1.859146	
Prob(F-statistic)	0.000000			
Inverted AR Roots	-.46			

Breusch-Godfrey Serial Correlation LM Test:

F-statistic	5.332291	Prob. F(1,24)	0.0299
Obs*R-squared	5.453673	Prob. Chi-Square(1)	0.0195

8. Germany

Dependent Variable: LOG(X1)

Method: Least Squares

Date: 06/10/11 Time: 17:20

Sample: 1980 2009

Included observations: 30

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-7.045669	2.719250	-2.591034	0.0157
LOG(X2)	-0.068648	0.013828	-4.964558	0.0000
LOG(X3)	0.598279	0.288521	2.073606	0.0486
LOG(X1(-1))	0.311590	0.125255	2.487640	0.0199
LOG(@TREND)	-0.311659	0.125846	-2.476501	0.0204
R-squared	0.854032	Mean dependent var	-3.391656	
Adjusted R-squared	0.830677	S.D. dependent var	0.062597	
S.E. of regression	0.025758	Akaike info criterion	-4.329124	
Sum squared resid	0.016587	Schwarz criterion	-4.095592	
Log likelihood	69.93687	Hannan-Quinn criter.	-4.254415	
F-statistic	36.56767	Durbin-Watson stat	2.181757	
Prob(F-statistic)	0.000000			

Breusch-Godfrey Serial Correlation LM Test:

F-statistic	0.480490	Prob. F(1,24)	0.4949
Obs*R-squared	0.588824	Prob. Chi-Square(1)	0.4429

9. United States of America

Dependent Variable: LOG(X1)

Method: Least Squares

Date: 06/10/11 Time: 20:14

Sample: 1980 2009

Included observations: 21

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-6.666853	1.216216	-5.481634	0.0001
LOG(X2)	-0.039265	0.012029	-3.264059	0.0049
LOG(X3)	0.587281	0.120411	4.877301	0.0002
LOG(X1(-1))	0.413066	0.075133	5.497779	0.0000
LOG(@TREND)	-0.264608	0.054757	-4.832441	0.0002
R-squared	0.904763	Mean dependent var	-2.686068	
Adjusted R-squared	0.880954	S.D. dependent var	0.032605	
S.E. of regression	0.011250	Akaike info criterion	-5.932710	
Sum squared resid	0.002025	Schwarz criterion	-5.684014	
Log likelihood	67.29345	Hannan-Quinn criter.	-5.878736	
F-statistic	38.00065	Durbin-Watson stat	2.078034	
Prob(F-statistic)	0.000000			

Breusch-Godfrey Serial Correlation LM Test:

F-statistic	3.029472	Prob. F(1,24)	0.0946
Obs*R-squared	3.362410	Prob. Chi-Square(1)	0.0667

10. Japan

Dependent Variable: LOG(X1)

Method: Least Squares

Date: 06/10/11 Time: 20:39

Sample: 1980 2009

Included observations: 30

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-5.654791	1.465938	-3.857457	0.0007
LOG(X2)	-0.036415	0.012457	-2.923130	0.0073
LOG(X3)	0.525836	0.148734	3.535408	0.0016
LOG(X1(-1))	0.692846	0.075393	9.189817	0.0000
LOG(@TREND)	-0.214212	0.063201	-3.389375	0.0023
R-squared	0.896038	Mean dependent var	-3.197881	
Adjusted R-squared	0.879404	S.D. dependent var	0.079201	
S.E. of regression	0.027504	Akaike info criterion	-4.197944	
Sum squared resid	0.018912	Schwarz criterion	-3.964411	
Log likelihood	67.96916	Hannan-Quinn criter.	-4.123235	
F-statistic	53.86786	Durbin-Watson stat	1.988117	
Prob(F-statistic)	0.000000			

Breusch-Godfrey Serial Correlation LM Test:

F-statistic	0.265703	Prob. F(1,24)	0.6109
Obs*R-squared	0.328492	Prob. Chi-Square(1)	0.5665

Bibliography

- Abdel-Khalek, G., 1988. Income and price elasticities of energy consumption in Egypt : A time-series analysis. *Energy Economics*, 10(1), pp.47-58.
- Adelman, M.A., 2002. World oil production & prices 1947-2000. *The Quarterly Review of Economics and Finance*, 42(2), pp.169-191.
- Agung, G., 2009. Time Series Data Analysis using EViews. John Wiley & Sons (Asia) Pte Ltd.
- Altinay, G., 2007. Short-run and long-run elasticities of import demand for crude oil in Turkey. *Energy Policy*, 35(11), pp.5829-5835.
- Askari, H. & Cummings, J.T., 1977. Estimating Agricultural Supply Response with the Nerlove Model: A Survey. *International Economic Review*, 18(2), pp.257-292
- Awerbuch, S. & Sauter, R., 2006. Exploiting the oil-GDP effect to support renewables deployment. *Energy Policy*, 34(17), pp.2805-2819.
- Baltagi, B., 2005 Econometric Analysis of Panel Data-Third Edition. John Wiley and Sons Ltd.
- Braulke, M., 1982. A Note on the Nerlove Model of Agricultural Supply Response. *International Economic Review*, 23(1), pp.241-244.
- Breitenfellner A., Cuaresma C.J. & Keppel C., 2009. Determinants of Crude Oil Prices: Supply, Demand, Cartel or Speculation? *Monetary Policy & the Economy*, (4), pp.111-136.
- Cochrane, D. & Orcutt, G.H., 1949. Application of Least Squares Regression to Relationships Containing Auto- Correlated Error Terms. *Journal of the American Statistical Association*, 44(245), pp.32-61
- Commission on Oil Independence, 2006. Making Sweden an OIL-FREE Society.
- Cooper J., 2003. Price elasticity of demand for crude oil: estimates for 23 countries. *OPEC Review*, 27(1), pp.1-8.
- Cryer. J., 2008. Time Series Analysis with Applications in R-Second Edition. Springer Edition.
- Danish Commission on Energy Climate Policy, 2010. Green Energy: The road to a Danish energy system without fossil fuels.
- Dargay, J. & Gately, Dermot, 1994. *The Response of Wolrd Energy and Oil Demand to Income Growth and Changes in Oil Prices*, C.V. Starr Center for Applied Economics, New York University.

- Dées, S. et al., 2007. Modelling the world oil market: Assessment of a quarterly econometric model. *Energy Policy*, 35(1), pp.178-191.
- Energy Policy Statement 2010, Danish Energy Agency, 2010.
- Gang Liu, 2004. *Estimating Energy Demand Elasticities for OECD Countries. A Dynamic Panel Data Approach*, Research Department of Statistics Norway.
- Gately, D. & Huntington, H.G., 2001. *The Asymmetric Effects of Changes in Price and Income on Energy and Oil Demand*, C.V. Starr Center for Applied Economics, New York University.
- Ghosh, S., 2009. Import demand of crude oil and economic growth: Evidence from India. *Energy Policy*, 37(2), pp.699-702.
- Ghouri, S.S., 2001. Oil demand in North America: 1980-2020. *OPEC Review*, 25(4), pp.339-355.
- Gujarati, D., 2009. Basic Econometrics-Fifth Edition. The McGraw-Hill Companies.
- Hamilton, J., 2009. Causes and Consequences of the Oil Shock of 2007-08. *Brookings Papers on Economic Activity*, 40(1) pp.215-283.
- Hirsch, R.L., 2008. Mitigation of maximum world oil production: Shortage scenarios. *Energy Policy*, 36(2), pp.881-889.
- IEA, 2004. Analysis of the Impact of High Oil Prices on the Global Economy.
- IEA, 2005. Energy Statistics Manual
- IEA, 2006. Energy Policies of IEA Countries: Denmark Review.
- IEA, 2007a. Energy Policies of IEA Countries: Finland Review.
- IEA, 2007b. Energy Policies of IEA Countries: Germany Review.
- IEA, 2007c. Energy Policies of IEA Countries: USA Review
- IEA, 2008a. Energy Policies of IEA Countries: Sweden Review.
- IEA, 2008b. Energy Policies of IEA Countries: Japan Review.
- IEA, 2009a. Energy Policies of IEA Countries: Portugal Review.
- IEA, 2009b. Energy Policies of IEA Countries: Spain Review.
- IEA 2009c Energy Policies of IEA Countries: Turkey Review.
- IEA 2009d Energy Policies of IEA Countries: Italy Review.
- IEA, 2010a. Key World Energy Statistics.

- IEA, 2010b. World Energy Outlook.
- IEA, 2010c. Energy balances of OECD countries
- Jian-Ling Jiao, Ying Fan & Yi-Ming Wei, 2009. The structural break and elasticity of coal demand in China: empirical findings from 1980-2006. *International Journal of Global Energy Issues*, 31(3), pp.331-344.
- Jones, C., 2002. Introduction to Economic Growth-Second Edition. W.W Norton & Company.
- Kaufmann R., Karadeloglou P., & Filippo di Mauro, 2008. *Will oil prices decline over the long run?*, European Central Bank.
- Krichene, N., 2002. World crude oil and natural gas: a demand and supply model. *Energy Economics*, 24(6), pp.557-576.
- Maddala, G., 1988. Introduction to Econometrics-Second Edition. McMillan Publishing Company.
- Mankiw, G., 2006. Principles of Microeconomics-Fourth Edition. South-Western College Publications.
- Myers, E., Palmer, K. & Paul, A., 2009. A Partial Adjustment Model of U.S. Electricity Demand by Region, Season, and Sector. *Resources for the future*, April 2009.
- Narayan, P.K. & Smyth, R., 2007. A panel cointegration analysis of the demand for oil in the Middle East. *Energy Policy*, 35(12), pp.6258-6265.
- Nerlove, M. & Addison, W., 1958. Statistical Estimation of Long-Run Elasticities of Supply and Demand. *Journal of Farm Economics*, 40(4), pp.861-880.
- Nerlove, M., 1956. Estimates of the Elasticities of Supply of Selected Agricultural Commodities. *Journal of Farm Economics*, 38, pp.496-509
- OPEC, 2010. World Oil Outlook.
- Olsen, O., 1988 Modelling demand for natural gas. A review of various approaches. Statistic Sentralbyra.
- Pesaran, M.H., Shin, Y., Smith, R., 2001. Bounds testing approaches to the analysis of level relationships. *Journal of Applied Econometrics* 16, 289–326
- Pesaran, M.H., Shin, Y., 1999. An autoregressive distributed lag modelling approach to cointegration analysis. In: Storm, S. (Ed.), *Econometrics and Economic Theory in the 20th Century: The Ragnar Frisch Centennial Symposium*. Cambridge University Press, Cambridge, pp. 1–31 (Chapter 11)

- Stevens, P., 1997. Increasing global dependence on Gulf oil. *Energy Policy*, 25(2), pp.135-142.
- Swedish Energy Agency, 2010. Energy in Sweden 2010.
- Thejll, P. & Schmith, T., 2005. Limitations on regression analysis due to serially correlated residuals: Application to climate reconstruction from proxies. *Journal of Geophysical Research*, 110, p.6 PP.
- Thiele, R., 2000. *Estimating the Aggregate Agricultural Supply Response: A Survey of Techniques and Results for Developing Countries*, Kiel Institute for the World Economy.
- Wittenberg, J., 1974. Nerlove's Theory of Adaptive Expectations: Some Problems of Application. *Journal of Agricultural Economics*, 25(3), pp.331-334.
- Wooldridge, J., 2009 *Introductory Econometrics: A modern approach-Second Edition*. South Western College.
- Wurzel E., Willard L., & Ollivaud P., 2009. *Recent Oil Price Movements: Forces and Policy Issues*, OECD Publishing.
- Xiong, J. & Wu, P., 2009. An analysis of forecasting model of crude oil demand based on cointegration and vector error correction model (VEC). In *2008 International Seminar on Business and Information Management, ISBIM 2008*. pp. 485-488.
- Ziramba, E., 2010. Price and income elasticities of crude oil import demand in South Africa: A cointegration analysis. *Energy Policy*, 38(12), pp.7844-7849.

Internet Sources

British Petroleum (BP). Statistical Review of World Energy 2010.

<http://www.bp.com/sectionbodycopy.do?categoryId=7500&contentId=7068481>

International Energy Agency. Statistics and Balances.

<http://www.iea.org/stats/index.asp>

U.S Energy Information Administration (EIA), Statistics and Data.

<http://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=RBRTE&f=M>

World Bank. The World DataBank, Statistics and Data.

<http://databank.worldbank.org/ddp/home.do?Step=1&id=4>